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MM&T FIBER-REINFORCED PLASTIC HELICOPTER TAIL ROTOR ASSEMBLY (PULTRUDED SPAR)

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APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

This report documents the manufacturing methods and technology (MM&T) efforts involved in the design refinement, fabrication, and structural testing of a fiber-reinforced plastic helicopter tail rotor. A pultrusion manufacturing process was established and successfully demonstrated for the fabrication of the YUH-60A graphite-epoxy flexbeam tail rotor spar. However, during actual flight test of the prototype YUH-60A helicopter, increased design load requirements were established that resulted in design modification to the production UH-60A BLACK HAWK tail rotor. Although the viability of the pultrusion manufacturing process was successfully demonstrated for the prototype tail rotor, the program was terminated because the cost effectiveness and producibility of the pultruded tail rotor spar for the UH-60A production helicopter were no longer sufficiently significant to warrant a change in the production fabrication methods.

This report has been reviewed by the Applied Technology Laboratory and is considered to be technically sound. It is published for the exchange of information and the stimulation of future pultrusion manufacturing process applications.

The technical monitor for this program was Mr. Dan Good, Structures Technical Area, Aeronautical Technology Division.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This program was directed at establishing the pultrusion process for the manufacture of helicopter tail rotor spars as a means of lowering manufacturing cost without sacrificing structural performance and keeping design changes to a minimum. The pultrusion process capability was successfully demonstrated by designing, fabricating, and testing a full-size tail rotor spar assembly for the YUH-60A prototype helicopters. Although the pultrusion process was determined to be a viable manufacturing fabrication method, the program was terminated prior to completion because the cost effectiveness and producibility of

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the pultrusion process as compared with present UH-60A BLACK HAWK production techniques are not sufficiently significant to warrant a change in manufacturing fabrication method at this time.

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SUMMARY

The original objective of this manufacturing methods and technology (MM&T) program was to develop the pultrusion manufacturing process for cost-effective fabrication of flexbeam-type tail rotors without sacrificing structural performance and keeping design changes to a minimum. The Sikorsky YUH-60A UTTAS prototype tail rotor assembly was selected as the demonstration article for this MM&T program because the uniaxial continuous tip-to-tip graphite-epoxy flexbeam spar was particularly amenable to pultrusion fabrication. Further, the introduction of a pultruded spar into the production version of the aircraft was highly feasible within the time frame of the Army Production Award. Based on the scope of work of the MM&T program at that point in time, it was felt that the pultrusion manufacturing technology developed in this program would be readily incorporated into the production version of the aircraft with reduced cost as compared to the current hand layup fabrication of the production spar.

The original MM&T contract was directed at the prototype YUH-60A UTTAS tail rotor design and used the prototype design as a baseline for comparison of manufacturing cost, producibility, and structural test results. In general, the subject MM&T program was technically successful. However, as a result of increased design load requirements obtained during actual flight evaluation of the prototype UTTAS aircraft, modifications were made to the production UH-60A BLACK HAWK tail rotor design that subsequently impacted this MM&T program. The primary modification to the production version of the tail rotor spar was a major design change in the torque rib/spar joint. This change required a redirection of the MM&T program in order to maintain direct applicability to the production tail rotor design. The change also resulted in a more complicated pultruded spar design at this location along the spar.

Static testing of the full-size prototype pultruded spar root end was performed and the results exceeded the original prototype UTTAS spar design requirements. The static test results also indicated that the root end design was basically adequate to meet the new increased ultimate load design requirements of the production design BLACK HAWK spar.

Fatigue testing of the pultruded spar root end demonstrated that this configuration met the original design load requirements of the prototype UTTAS spar, but was unacceptable with respect to meeting the increased production design load requirements. Necessary design modifications were identified and resulted in a new pultruded root end design that was capable of meeting the new higher design load requirements.

As a result of the design modification that changed the torque rib design on the production BLACK HAWK spar assembly, portions of the full-scale static and fatigue specimen testing and evaluation phase were deleted from the program scope of work. A Final Design Manufacturing Method Assessment phase was then incorporated into the program's scope of work. This new effort involved redesigning the pultrusion root end, incorporating all the

design changes in the production BLACK HAWK tail rotor assembly, inputting the data obtained from the previous phases into the design fabrication, static testing a pultruded torque rib spar specimen, and fatigue testing of a pultruded outboard tail rotor blade specimen. As the design of the pultruded torque rib and redesign of the root end was evolving, the production BLACK HAWK design was undergoing fatigue testing. Feedback from the fatigue tests resulted in additional design modifications to the production BLACK HAWK spar and was reflected simultaneously in the design of the pultruded spar. The design modifications held up the pultruded design and caused an additional slippage in the MM&T program schedule. This situation ultimately reduced the potential for significant cost savings and precipitated termination of the subject MM&T contract. Prior to termination, redesign of the pultruded spar root end and of various proposed designs of the new torque rib was accomplished.

It should be recognized that the original objective of developing the pultrusion manufacturing technology for flexbeam tail rotors has been achieved. A full-size pultruded tail rotor spar that met the original prototype UTTAS design requirements has been designed, fabricated, and static and fatigue tested successfully. The technical problems that were encountered during the program were primarily the results of the changing baseline tail rotor design.

PREFACE

This report was prepared by Sikorsky Aircraft Division of United Technologies Corporation, under the sponsorship of the U.S. Army Aviation Research and Development Command (AVRADCOM), St. Louis, Missouri, with technical monitorship by the Applied Technology Laboratory, U.S. Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia, under Contract DAAJ02-76-C-0001. The Army technical contract monitor was Mr. Dan Good of ATL. This final report covers work conducted from 29 August 1975 to 30 October 1978.

The authors wish to acknowledge the contribution and cooperation of Goldsworth Engineering, Inc.

Acknowledgement is also given to the following Sikorsky employees for their efforts and assistance in the design concept, stress analysis, mechanical testing, and material analysis of this program: E. F. Olster, A. T. Krauss, F. A. Rizzo, R. Gallagher, W. Kolesar and M. Dandorph.

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INTRODUCTION

Background

The continuing demand of the aerospace industry for the manufacture of more efficient aircraft components and structures has led to the extensive use of advanced composite materials for highly loaded primary aircraft structural components. While material costs are a primary factor in selection of composite components, very often the most significant cost driver in manufacturing is labor costs. High labor costs are especially evident when hand layup techniques are used. In [illegible] to minimize fabrication costs of advanced composite structural components, it is essential to exploit design and manufacturing methods and techniques that conserve hand layup, preimpregnated (prepreg) material application, and cutting operations. The use of pultrusions is one manufacturing process that has significant potential to achieve this end.

Pultrusion Process Description

Pultrusion is a process that forms structural shapes by pulling preimpregnated oriented filaments through a heated die (Figure 1). The pultrusion process offers the potential for producing highly cost-effective components. This concept is particularly applicable to the UTTAS-type helicopter tail rotor blade spar (Figure 2). Therefore, this manufacturing methods and technology program, directed toward the YUH-60A tail rotor blade spar production application, was initiated.

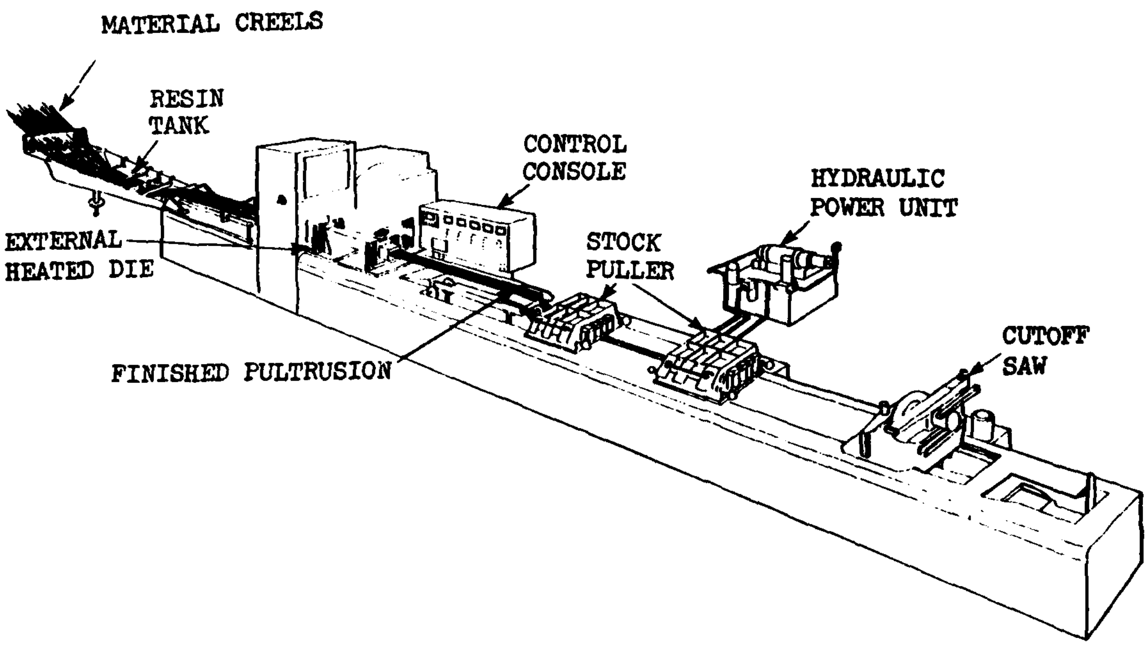

Figure 1. Typical Pultrusion Process Facility.

Figure 2. YUH-60A UTTAS Helicopter, Depicting Closeup of Tail Rotor Blade Assembly.

UTTAS Tail Rotor Application

One of the most significant helicopter design concepts developed in the past decade has been composite bearingless rotors. A composite bearingless rotor was designed and used in the prototype UTTAS aircraft and is currently incorporated in the production BLACK HAWK helicopter (Figure 3). The heart of the bearingless rotor system is the advanced composite flexbeam spar, which is light in weight, stiff in bending, and very flexible in torsion. The flexbeam consists primarily of a 0° unidirectional rectangular-shaped AS graphite-epoxy spar, which is continuous from one blade tip, through the hub, to the tip of the opposite blade. The spar is approximately 10 feet long, 5 inches wide by 0.6 inches thick at the inboard hub region, tapering to 3 inches wide by 0.3 inches thick at the outboard tip end. Currently, the tail rotor blade spar for the UH-60A BLACK HAWK helicopter is fabricated by laying precut individual plies of 0.012-inch-thick preimpregnated material into a mold to obtain the required thickness dimension (approximately 250 individual plies) and curing the assembly in an autoclave to produce a homogeneous composite spar. Because the cost of cutting prepreg into various lengths and using hand layup is high, this method of fabrication is costly. Use of pultrusion to replace the cutting and hand layup processes appeared particularly amenable to this configuration and was, therefore, selected to demonstrate reduced manufacturing cost for a future production application.

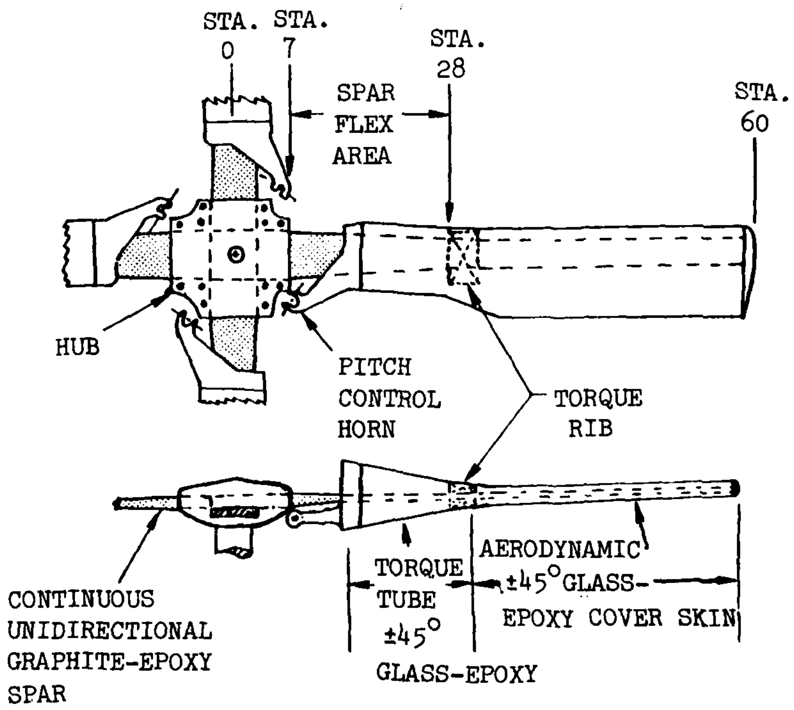

Figure 3. UTTAS Bearingless Tail Rotor Design.

Program Scope and Methodology

The primary aim of this MM&T program was to demonstrate the applicability of the pultrusion fabrication process for the manufacture of flexbeam-type tail rotors for use on the U. S. Army BLACK HAWK helicopter, the production version of the prototype UTTAS helicopter. The scope of work included the determination of the producibility and cost effectiveness of pultrusion technology in this application without sacrificing structural performance and keeping design changes to a minimum. The method recommended to demonstrate the pultrusion capability was to design, fabricate, and test a complete tail rotor assembly. The prototype UTTAS tail rotor design was to be used as a baseline for comparison of manufacturing cost, producibility, and structural test results for pultruded tail rotor components.

The program was planned originally in five phases: Phase I - Design and Manufacturing Concepts, Phase II - Small-scale Specimen Testing, Phase III - Full-size Static and Fatigue Specimen Fabrication, Phase IV - Full-scale Static and Fatigue Specimen Testing and Evaluation, and Phase V - Documentation of the data obtained.

Phase I encompassed a review of the prototype UTTAS rotor assembly design and fabrication in order to determine their applicability for manufacture by the pultrusion process. Preliminary design concepts were to be formulated and stress analyses were to precipitate two basic spar designs. Sub-scale and full-scale risk reduction tests were to be conducted on the basic preliminary design concepts evolved.

Phase II included static and fatigue laminate testing at various temperatures to verify that the material selected for pultrusion met the current requirements of the prepreg material specification used in the UTTAS prototype spar.

Phase III involved fabrication of full-scale root end and tip weight attachment pultruded component hardware specimens for testing in Phase IV.

Phase IV entailed actual static and fatigue testing of pultruded component hardware specimens to failure and evaluation of the test data. In addition, a 50-hour whirl test of a complete rotor assembly with pultruded components was planned.

During the final phases of this program, changes evolved in the scope and methodology and were directly related to design modifications made to the baseline production prepreg UH-60A BLACK HAWK spar. These modifications resulted in deletion of the original plan for a full-scale whirl test and incorporated a new Phase V item termed "Final Design Manufacturing Method Assessment". This effort was directed at redesigning the prototype pultruded spar to incorporate the configuration changes necessary to compensate for the increased loading requirements and design changes established for the production UH-60A BLACK HAWK tail rotor spar. Details of the changes and the reasons for the redesign are discussed within the body of this report.

PHASE I - DESIGN AND MANUFACTURING CONCEPTS

The Design and Manufacturing Concepts phase of the program reviewed the prototype YUH-60A UTTAS tail rotor assembly design and fabrication process and ascertained what components were directly applicable for manufacture by the pultrusion process. Preliminary design concepts for the pultruded spar were formulated and stress analysis resulted in two promising basic design and manufacturing concepts (Concepts I and II) which were considered compatible with the prepreg components current at that point in time. Subscale and full-size risk reduction tests were conducted on the two evolved basic preliminary design concepts and together with a manufacturing cost assessment resulted in selection of a single proposed design concept for the pultruded spar. The design ultimately selected, Concept II, used a partially cured or "B" staged unidirectional graphite-epoxy pultrusion, rather than a buildup from fully cured details as proposed in the Concept I design.

Design Concepts

Prior to initiation of preliminary design layout and manufacturing concepts for a pultruded fiber-reinforced helicopter tail rotor assembly, review of the prototype UTTAS tail rotor design and fabrication process was performed. Results of this review disclosed that the spar and counterweight detail components were amenable to fabrication using the pultrusion process. Table 1 summarizes the tail rotor assembly components and the applicability of the pultrusion process. Although a cost assessment indicated that both a pultruded counterweight and pultruded spar would be cost effective as compared to the existing designs, the scope of the contract was not broadened to include the pultruded counterweight. Therefore, the work effort continued on the spar only.

Preliminary design layouts and manufacturing concepts of pultruded spar details were generated using the prototype UTTAS tail rotor design and fabrication process as a baseline. This manufacturing approach for pultruded spar assemblies produced two promising design concepts. The first, Concept I, consisted of 0° graphite-epoxy fully cured pultruded material center strips sandwiched between fully cured external layers of 0° pultruded graphite-epoxy with $\pm 20^{\circ}$ braided graphite at the centerline. These components were to be adhesively bonded by vacuum bag and autoclave cure. The tapers in the spar configuration and the hole in the center spar root region would then be machined. Secondary bonding of a 90° unidirectional graphite-epoxy prepreg wrap was proposed to be applied on the external surface of the spar to complete the assembly. Figure 4 illustrates Concept I, the fully cured pultruded spar design layout and manufacturing concept.

Concept II was a design that used a 0° prepreg torpedo insert at the center spar root area. The "B" stage pultrusion with the torpedo insert is sandwiched between external layers of $\pm 20^{\circ}/0^{\circ}$ prepreg. The components are subsequently placed in a contoured mold (which eliminates any subsequent machining) and simultaneously cured in an autoclave. Secondary bonding of a 90° unidirectional graphite-epoxy wrap was proposed to be

TABLE 1. SUMMARY OF DESIGN AND FABRICATION PROCESS FOR TAIL ROTOR ASSEMBLY COMPONENTS AMENABLE TO PULTRUSION

Components	Present Configuration	Applicability of Pultrusion
Spar	. Hand layup of graphite-epoxy prepreg . Matched metal die molded	Yes
Counterweight	. Continuous lead wire interleaved with woven glass prepreg . Compression molded	Yes
Cover Skin	. $\pm45/90^\circ$ unidirectional glass-epoxy prepreg . Spanwise twist with changes in spanwise and chordwise thickness . Autoclave molded	No
Torque Rib	. $0^\circ/90^\circ$ layup of woven glass prepreg . Press molded to contour with thickness changes in both span and chord	No
Horn	. Aluminum forging	No
Tip Attachment	. Titanium plate	No

applied on the exterior surface. The hole at the center spar root region was to be machined to complete the assembly. Figure 5 illustrates the Concept II partially cured or "B" staged pultruded spar design layout and manufacturing concept.

In both concepts, the external envelopes and the balance of 0° and $\pm 20^\circ$ material selected were similar to the existing prepreg design to maintain common interfaces and stiffnesses.

Design Concept I was a high design risk venture because only 20 percent of the fibers are continuous from end to end and transfer of shear loads around the 2.75-inch-wide hole at the center spar root area is dependent on the adhesive bond to the external buildup plies. However, Concept I was a low-probability manufacturing risk due to the relative ease in bonding flat pultrusion components of constant cross section. Design Concept II was a low design risk endeavor closely resembling the conventional BLACK HAWK prepreg spar with 100 percent of the spar fibers continuous from tip to tip. This concept presented a high manufacturing risk because spreading the pultruded material and the cocure of partially cured or "B" staged pultruded material and uncured graphite-epoxy prepreg was beyond the current state of the art at the time and had to be developed as part of the program work effort.

The resin system specified by the Army for use in the pultrusion manufacture throughout the program was Epon 826/MPD/DMF which is a MIL-R-9300, Type I approved resin system. This resin system was previously characterized by Goldsworthy Engineering, Inc. (GEI), under Army Contract DAAJ02-75-0053, described in Reference 1, and found to be the most pultrudable system of the epoxies evaluated.

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[1] Jones, B. H., and Jakway, W., MM&T - PULTRUDED COMPOSITE STRUCTURAL ELEMENTS, Goldsworthy Engineering, Inc.; USAAMRDL Technical Report 76-5, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, December 1976, AD A035217.

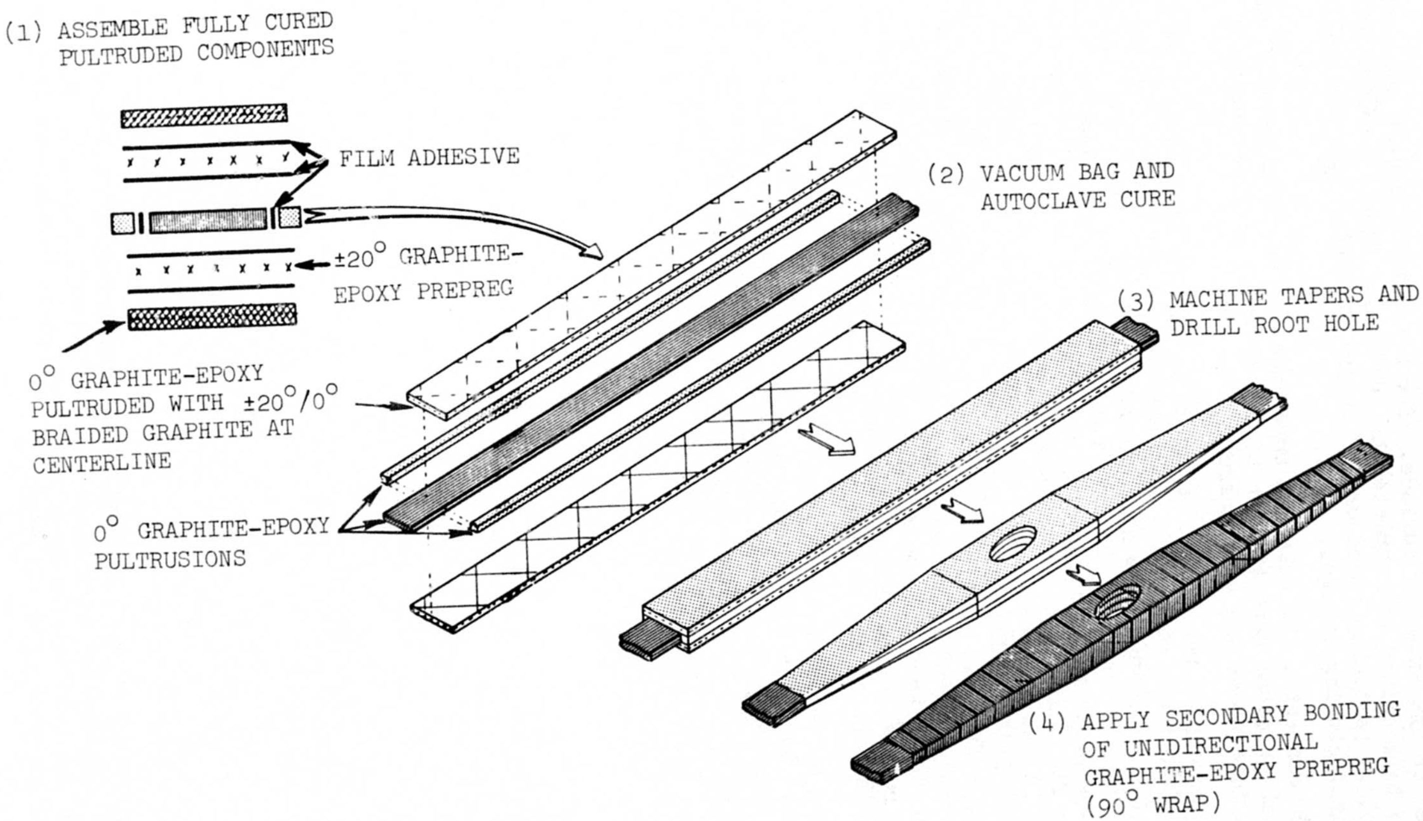


Figure 4. Concept I - Fully Cured Pultruded Spar Design Layout and Manufacturing Approach.

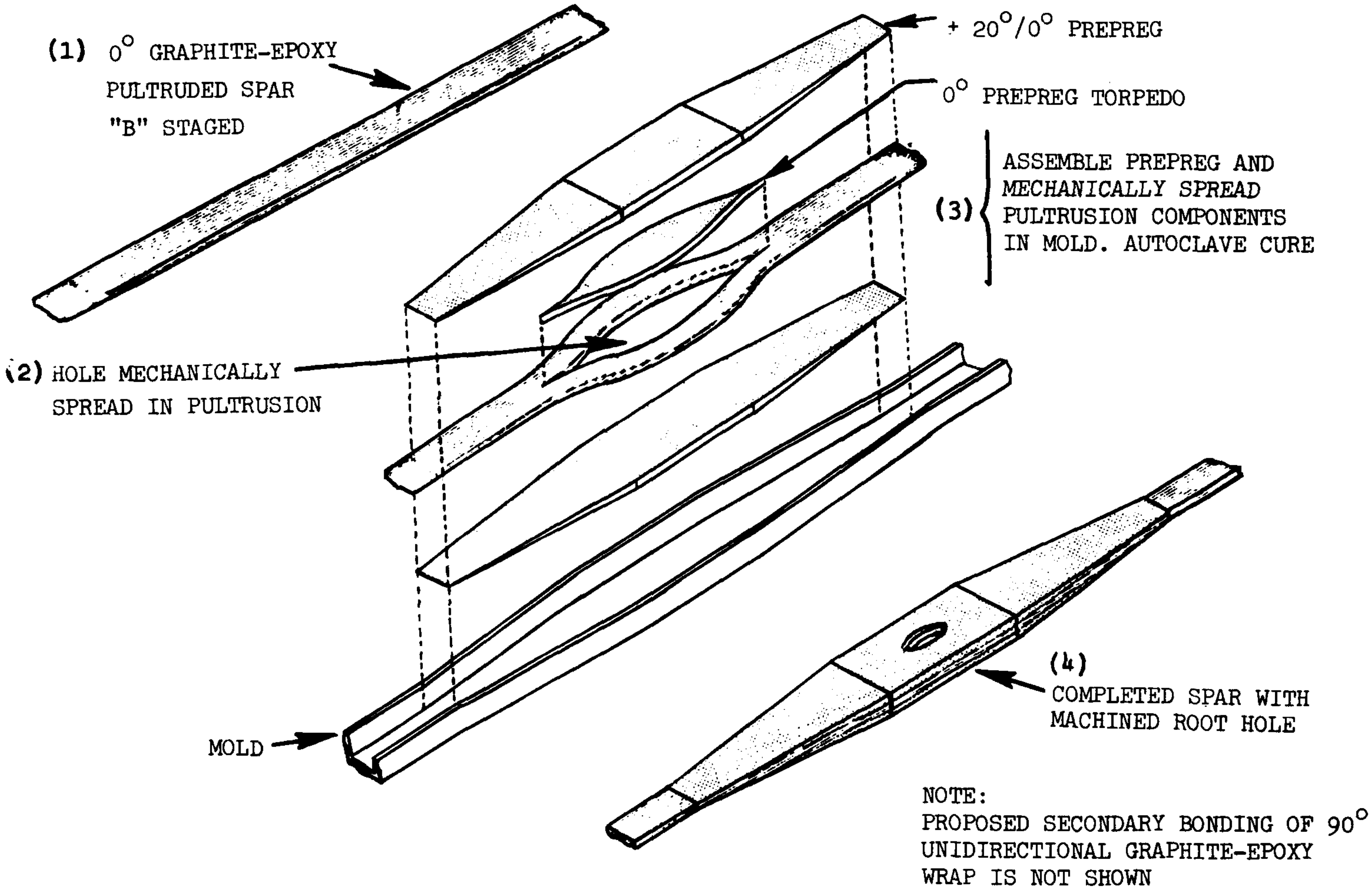


Figure 5. Concept II - Partially Cured or "B" Staged Pultruded Spar Design Layout and Manufacturing Approach.

Risk Reduction

Laminate Process. The laminates pultruded for all the Risk Reduction specimens were made to a 60 percent volume using Hercules AS fiber (10,000 filament/tow) and Epon 826/MPD/DMF resin system proportions as shown in Table 2.

TABLE 2. MATERIAL PROPORTIONS USED FOR PULTRUDED MATERIAL

Material	Part By Weight
Epon 826	100
m-phenylenediamine (MPD)	14
Dimethyl Formamide (DMF)	5

The viscosity of the resin bath was kept at 500 cps by maintaining a bath temperature of 100°F. The laminates used in the Phase I bonded joint evaluations were pultruded using processing parameters developed in Reference 1, i.e., 390°F die temperature and 12 inches per minute feed rate. Laminates requiring full cures were further oven cured at 175°F for 2 hours plus 300°F for 2 hours. Laminates requiring a gelled condition were bonded in the "as pultruded" condition. The laminates required for the Concept II process risk reduction specimens were prepared to evaluate and develop the mechanical spreading techniques required in the manufacturing of the full-size specimens. Two approaches, identified as Process A and Process B, were evaluated as shown in Table 3. Process A consisted of varying the pultrusion process parameters of speed and die temperature to obtain a pultruded material consistency that could be mechanically spread at the specimen's center section. Process B consisted of totally eliminating the resin from the specimen's center section, thus, allowing the dry fibers in that area to be readily spread. During the manufacturing operation, the eliminated resin would be replaced by the addition of liquid resin. Details of Process A and B are provided in the following paragraphs. Evaluation of the samples revealed the bulk or billowing of the Process B dry fiber area to be a greater possible manufacturing risk than possible resin buildup in the die associated with Process A. Efforts were directed toward optimizing Process A, and Process B work was stopped.

In order that an uncured or "B" staged pultrusion could be obtained, Process A specimens were pultruded using variations of the standard pultrusion processing rates. Table 3 is a matrix of the pultrusion parameters evaluated. A die temperature of 300°F and a feed of 3 inches per minute increased to 96 inches per minute resulted in the most visually uniform and pliable "B" staged pultrusion. The rate increase was accomplished by rapidly increasing the speed of the stock puller, allowing the material to move more rapidly

through the pultrusion die. The effect of low pultrusion temperature and high feed rates on the degree of die surface resin buildup was identified during the Phase I full-size specimen fabrication. Because the time between pultruding and assembly was greater than one week, a storage stability of the "B" staged pultrusion had been identified previously as a risk. The pultruded specimen, which was stored at 0°F for 30 days prior to shipment in dry ice, was found to be nonspreadable at room temperature. The specimen was subjected to elevated temperatures of 140-160°F before it could be readily worked. It was feared that by applying temperatures up to 160°F during assembly, premature gelation would occur. Therefore, the next specimen was evaluated after 1 week of storage and shipment. This pultruded material was found to be easily spreadable after warming to 120°F. This sample was used as the spar detail in the fabrication of the Concept II subscale static test specimen. As a result of the spreading experiments, it was intended that the spar mold that was used to mold the "B" staged specimens would be equipped with adjustable heat lamps to continuously heat the pultrusion during the assembly operation.

Two Process B specimens were pultruded with a portion of graphite dry of resin as a means of eliminating resin buildup on the die surfaces. The dry fiber was obtained by lowering the resin bath away from the graphite feed as it was pulled through the die. After visual examination of the sample, it was decided that the increased bulk and fragile nature of the dry fiber contributed to a greater manufacturing risk than optimizing Process A.

TABLE 3. CONCEPT II - PROCESS RISK REDUCTION MATRIX (a)

Process	Sample Identification	Die Temperature (°F)	Feed Rate (inches/min)	Condition of Center "B" Stage	Remarks
A	1	400	12	Hard	-
	2	400	18	Hard	-
	3	400	24	Hard	-
	4	350	60	Hard	-
	5	400 → 300 (decreasing)	18	Hard	-
	6	300	3 → 96 (increasing)	Soft (b)	Dry
	7	300	3 → 96	Soft (c)	Dry
B	8	400	12	Center of pul-trusion void of resin	Fiber bulk

(a) Sample size 1.35" wide x 0.17" thick x 36" long.

(b) Pultruded 26/Jan/76 and stored 30 days at 0°F prior to shipment and evaluation at Sikorsky.

(c) Incorporated into Concept II subscale static specimen.

Laminate Test. Both interlaminar shear and double overlap shear specimens were tested in order to evaluate the bonded joint between fully cured and gelled pultrusion laminates as required by the Concept I manufacturing process. The interlaminar shear strengths obtained with the bonded specimens are reported in Table 4. These results are approximately 50 percent of the value reported in Reference 1 for specimens without a bond joint. The mode of failure for all the interlaminar shear specimens was interply and not in the bond joint. Prior to test, the thickness of the specimens was machined to the spar thickness. It appeared that machining produced sufficient fiber damage to cause, or at least contribute to, low shear strengths.

Testing on nonmachined bonded specimens was conducted in order to evaluate the effects of machining on the interlaminar shear strength of bonded pultrusions. The results showed that the average interlaminar shear strength of five nonmachined bonded pultrusion specimens is 12,300 psi, which is well above the data listed in Table 4. The mode of failure for all of the nonmachined interlaminar shear specimens was in the midplane bond joint. Based on these results, it was concluded that the low interlaminar shear strength experienced previously was the result of damage caused by machining of the specimens.

Because of the inadequacy of the interlaminar shear specimens to provide shear strength data of the various adhesive systems, double overlap shear specimens were fabricated and tested. These specimens were fabricated using the candidate adhesive systems of Metlbond 1113, AF143, and EA9653. Figure 6 depicts the double overlap shear specimen configuration. Testing was conducted at room temperature and results are listed in Table 4. Metlbond 1113 adhesive yielded the highest tensile shear strength with AF143 and EA9653 following. Failure mode of the specimens ranged from substrate for the Metlbond to adhesive for the EA9653. Based on these results and other data, Metlbond 1113 was selected as the pultrusion bonding adhesive for Concept I.

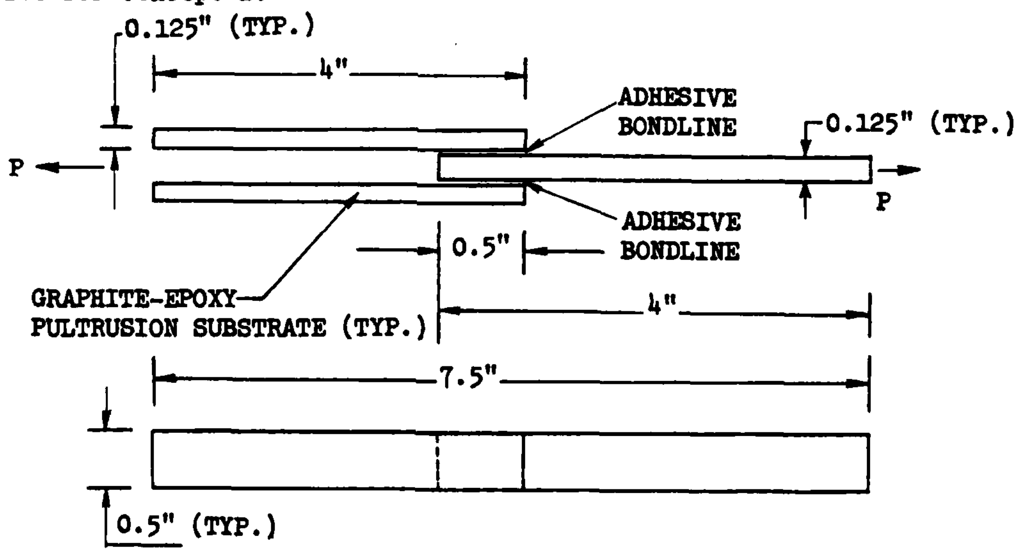


Figure 6. Double Overlap Shear Specimen Configuration.

TABLE 4. PHASE I - RISK REDUCTION TEST RESULTS (a)

Adhesive Tested	Interlaminar Shear Strength, (b) psi				Double Overlap Shear Strength (psi)
	Goldsworthy (e)		0.125 in. thick		
	Both sides fully cured	One side fully cured/one side gelled	Sikorsky	Goldsworthy	
NARMCO (1113)	7470	7460	9600	8300	3275 (c)
3M Co. (AF143)	6570	7150	-	11,000	2975 (c)
HYSOL (EA9653)	6660	6739	-	8550	2300 (d)

(a) Average of two tests conducted at room temperature.

(b) Tests conducted per American Society for Testing and Materials, (ASTM)D2344, "Apparent Horizontal Shear Strength of Reinforced Plastics by Short Beam Method". All failures were interlaminar (no adhesive failure).

(c) 90% graphite substrate failure, 10% adhesive.

(d) 80% adhesive, 20% substrate failure.

(e) Machined to 0.250 inch thick.

Concept I - Subscale Specimen

In order to confirm the pultruded spar stress analysis, i.e., that the stresses can be transferred through adhesive, a half-size, subscale specimen was constructed prior to the actual fabrication of the full-size static specimen. Hand layup and autoclave cure of graphite-epoxy prepreg (Reliable RAC 6350/AS) material was used. As a result of an adhesive test evaluation in both interlaminar shear and in double overlap shear, NARMCO Metlbond 1113 film adhesive was selected as the most favorable adhesive to bond the full-size and subscale specimens. The adhesive was cured at 250°F for 1 hour at 20-30 psi. Figure 7 shows the Concept I subscale static specimen design and Figure 8 depicts the actual hardware specimen.

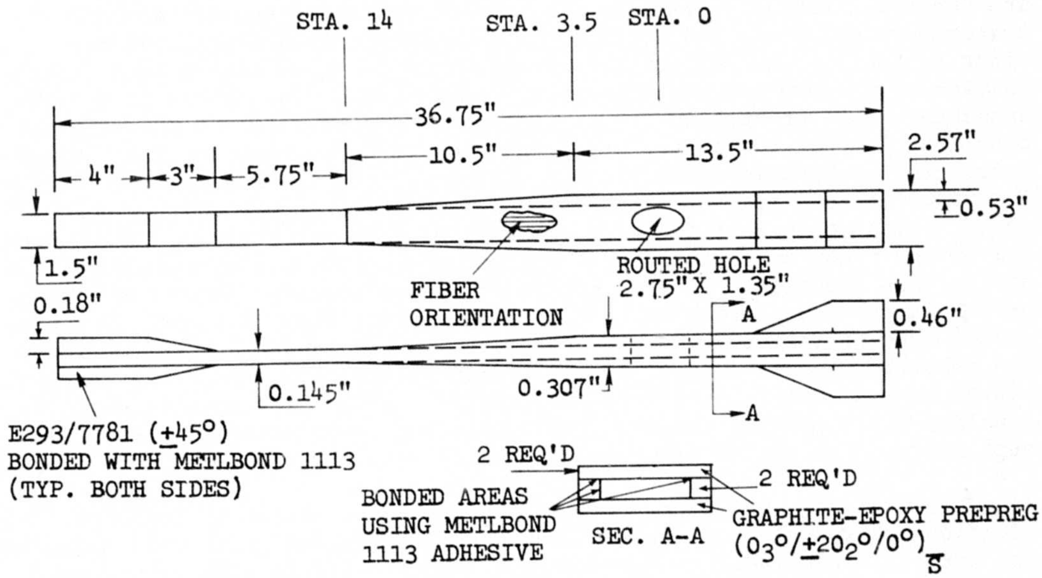


Figure 7. Concept I - Subscale Static Specimen Design.

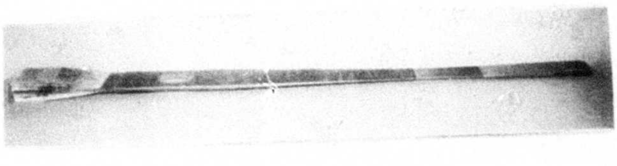


Figure 8. Concept I - Subscale Static Specimen Hardware.

Fabrication of the Concept I subscale static specimen consisted of machining the width taper in the detail right and left side strips prior to bonding the side strips to the constant cross section center strip. The thickness taper of the specimen was obtained by reducing the ply per inch of length during the hand layup operation of the external segments. The bonded detail center strips were subsequently bonded to the machined external segments. Precured fiberglass grippers were bonded at each end of the specimen prior to installation of the 90° graphite overwrap. The subscale assembly was autoclave cured. The hole in the root hub region was machined to complete the specimen fabrication. Coin tap inspection of the laminate and adhesive bond joints was used as the criterion to determine sound and homogeneous specimens. No evidence of voids, disbonds, or any other anomalies was detected.

The Concept I subscale specimen was tested axially in tension at room temperature and fractured at 25,500 pounds which, when normalized for fiber content, is 82 percent of the predicted design ultimate load. Examination of the specimen revealed that fracturing of the fibers in the hub attachment hole at Station 1.0 was followed by separation of the vertical bond interface of the center strip and side strip at Station 10.5. Figure 9 depicts the locations and closeup views of each of the separated details. The vertical bond fracture at Station 1.0 revealed a poor quality bond joint, which was associated with insufficient lateral pressure during bonding of the right and left side strips to the constant cross section center strip. The capability of the thick bondline to transfer shear loads may have been reduced sufficiently to cause premature fiber failure. The predicted area of failure was outboard of the bonded tapers at Station 10.5. The subscale Concept I test results indicated that the design was marginal, but no manufacturing risks were anticipated. These test results and conclusions confirmed the original previously expressed statements that Concept I is a high design risk and a low manufacturing risk.

In order that the structural risk of the Concept I design be lessened, additional off-angle (one each ± 20°) graphite prepreg plies were added to the internal interfaces of the external segments and to both interfaces on the internal strips for the Phase I, Concept I full-scale specimen. The addition of off-angle plies at the interface locations was to facilitate the transfer of shear loads around the hole at the root area. To supplement the autoclave pressure when bonding the vertical joint of the internal side strips for the full-scale specimen, mechanical force was applied to insure sufficient lateral pressure to produce a structural bondline of 0.005 - 0.008 inches.

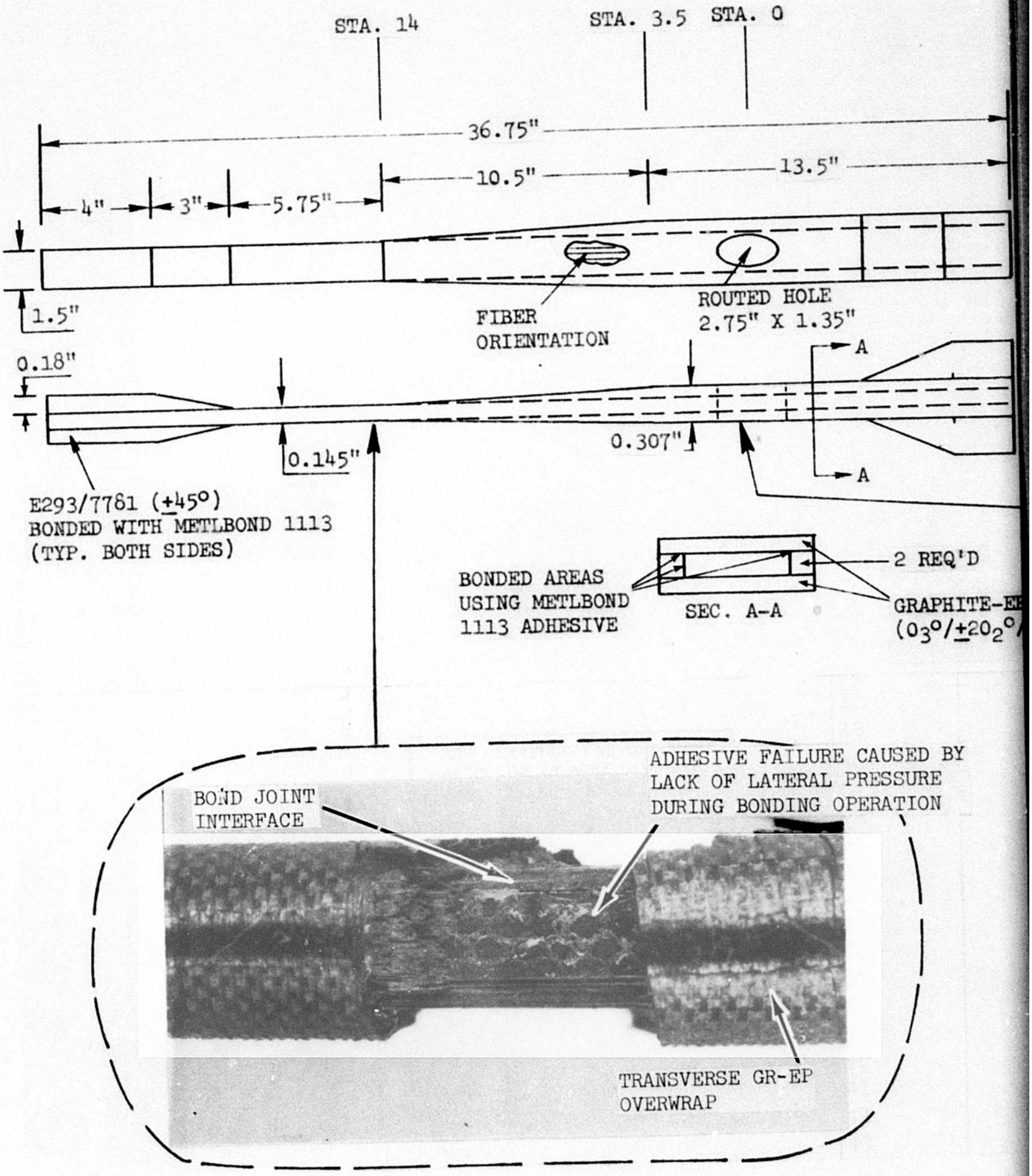
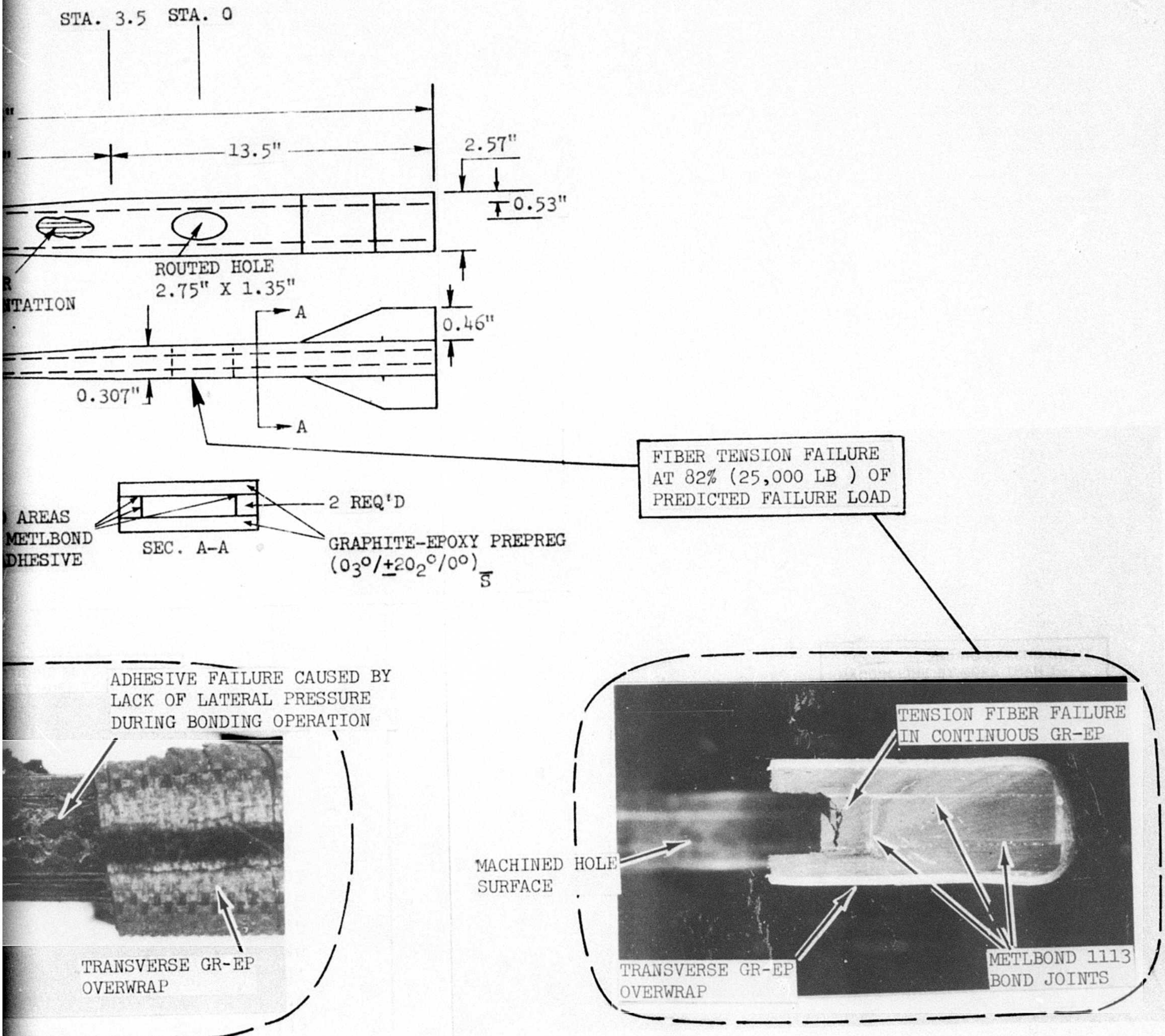


Figure 9. Concept I - Subscale Static Specimen Detail Failures.



le Static Specimen Detail Failures.

Concept II - Subscale Specimen

In order to determine the pultrudability of uncured "B" stage material, the feasibility of mechanically spreading "B" stage material, and the effect of the "B" stage condition on dimensional relaxation, a pultrusion process risk reduction parameter study for Concept II was conducted. In addition, the risk reduction study determined the bulk factor required to adequately compact the "B" stage pultrusion during molding. The study included the feasibility of pultruding a "B" stage or uncured section of a gelled pultrusion material by reducing the elevated die temperature and increasing the speed of the resin-coated filament material as it proceeded through the die. Once these parameters were determined, fine tuning of the process was established for process repeatability. Experiments were conducted to investigate the Concept II mechanical spreading techniques. Results of the experiment demonstrated that Concept II is a viable process if the graphite-epoxy material can be pultruded in a "B" stage condition. Pultruding the material in a "B" stage condition will minimize fiber distortion as a result of spreading. Risk reduction work to develop the Concept II processing parameters included using a 350°F curing unidirectional graphite-epoxy prepreg tape in place of the graphite-epoxy pultrusion. A laminate simulating the pultrusion consisting of 52 layers of 3-inch-wide by 24-inch-long prepreg was laid up and cold compacted. The spreading device consisted of two Teflon-coated wooden wedges, 2 inches wide at the base by 6-3/4 inches long by 3/4 inch thick, and tapered to a 12° angle at the apex. Starting at the center of the layup, the wedges were hand driven into the material and away from the center as illustrated in Figure 10. Considerable distortion and twisting of the layup was observed as the displacement took place. A simple precompaction cycle in a small laboratory press eliminated all of the distortion prior to curing. Cure was accomplished in an autoclave leaving the wooden wedges in place and using a perforated aluminum caul plate. Microscopic examination of the cured laminate cross section revealed no evidence of any fiber distortion. Figure 11 shows the cured laminate and spreading wedges.

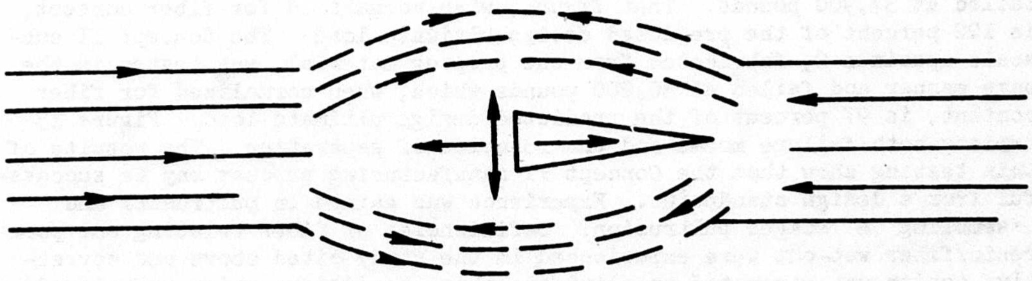


Figure 10. Diagrammatic Illustration of Spreading Technique.

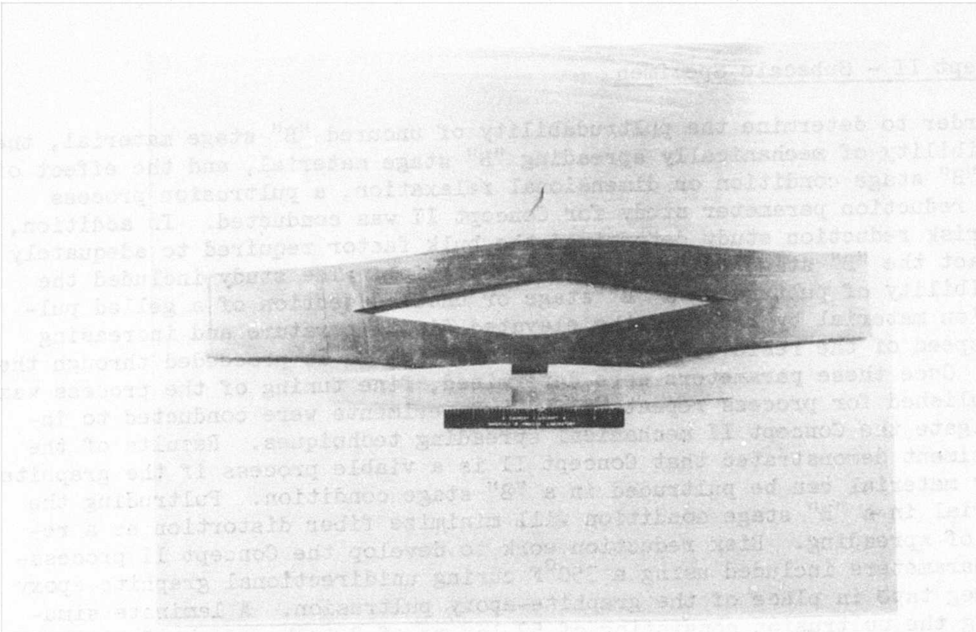


Figure 11. Cured Mechanically Spread Graphite-Epoxy Laminate and Spreading Wedges.

To verify the Concept II spar stress analysis and reduce the risk of the manufacturing process prior to the fabrication of the full-size static specimen, two subscale specimens were fabricated using a "B" stage pultrusion spar section from the Phase I risk reduction effort, and a graphite-epoxy prepreg, NARMCO 5209, root buildup detail. As a result of the Concept I subscale static specimen test, the ply orientation of the root buildup was modified to a unidirectional off-angle orientation in an attempt to ease shear transfer burden. Figure 12 shows the subscale specimen design. The Concept II subscale specimen 1, fabricated from the pultruded material, was tested axially in tension at room temperature and failed at 37,900 pounds. That figure, when normalized for fiber content, is 122 percent of the predicted design ultimate load. The Concept II subscale specimen 2, fabricated from the prepreg material, was tested in the same manner and failed at 30,200 pounds which, when normalized for fiber content, is 97 percent of the predicted design ultimate load. Figure 13 depicts both failure modes and the location of separation. The results of this testing show that the Concept II manufacturing process may be successful from a design standpoint. Experience was gained in pultruding and assembling "B" staged pultrusion. Deficiencies of fiber twisting and poor resin/fiber wet-out were experienced in the study cited above and corrective action was generated to eliminate these conditions prior to pultruding the full-size specimens.

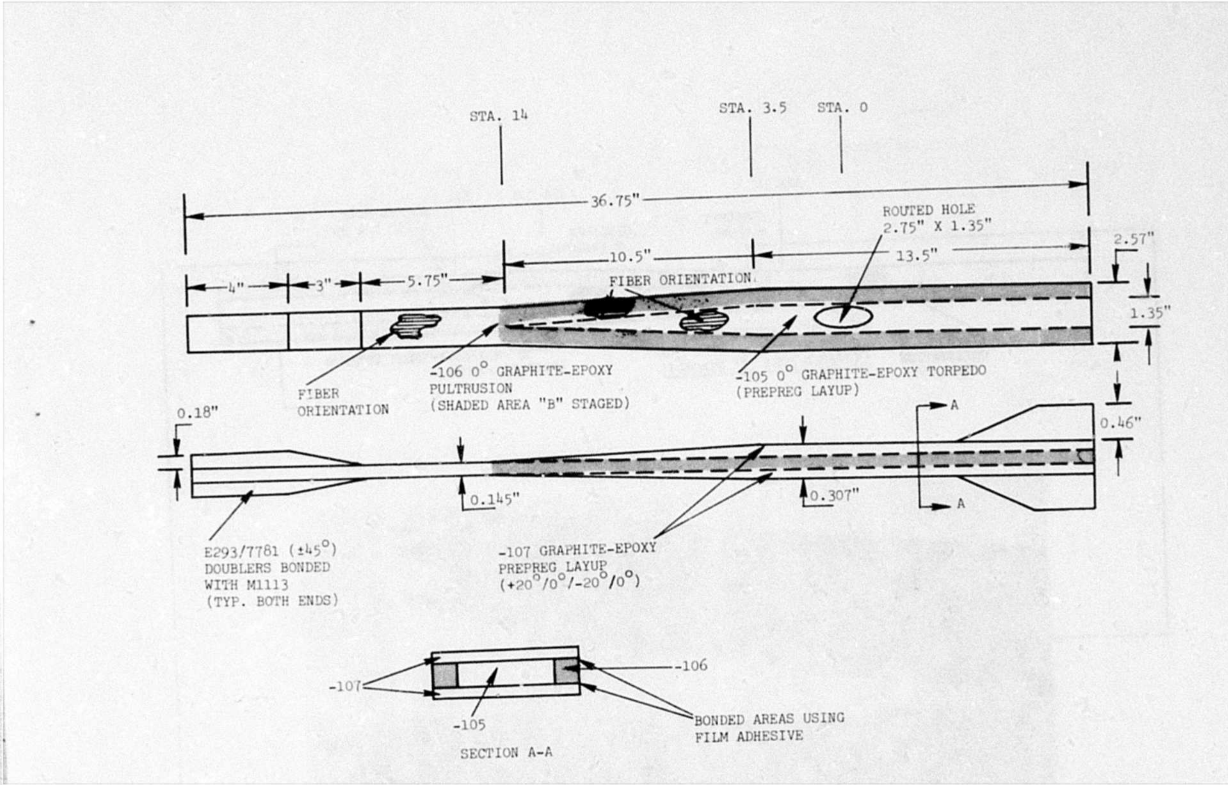
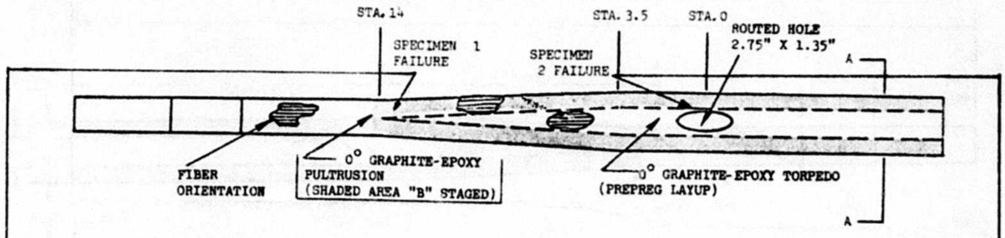
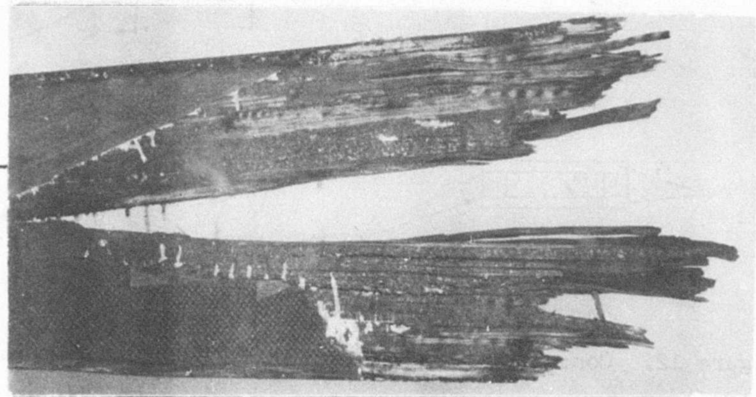


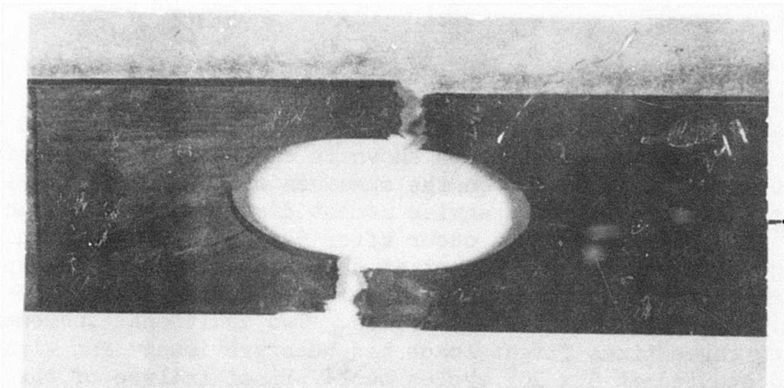
Figure 12. Concept II - Subscale Static Specimen Design.

Fatigue testing of the Concept II subscale specimen was performed in a cantilever beam bending facility as shown in Figure 14. Application of the vibratory flatwise moments on the specimen without centrifugal load did not duplicate the flight spanwise moment distribution for specimen 1. Failure of the specimen did not occur after 5×10^6 cycles, at which time the testing was stopped. The moment at the outboard end of the specimen was accelerated to three times that experienced during high-speed flight before failure occurred at 4×10^6 cycles. Two additional increments at levels below three times flight loads had been previously run without failure and stopped at 5×10^6 cycles each. Final failure of the specimen occurred at three times flight loads. The spar separation was located 18 inches from the center of the hole. Specimen 2 accumulated over 10^7 cycles of accelerated fatigue loading without fracture. Sufficient centrifugal force was applied to the specimen to more closely represent the flight moment distribution. Figure 15 summarizes the fatigue testing data.





SPECIMEN 1 FAILED AT 122% (37,900 LB) OF PREDICTED FAILURE LOAD.



SPECIMEN 2 FAILED AT 97% (30,200 LB) OF PREDICTED FAILURE LOAD. FABRICATED PREPREG THROUGHOUT SPECIMEN.

Figure 13. Concept II - Subscale Static Specimen Detail Failures.

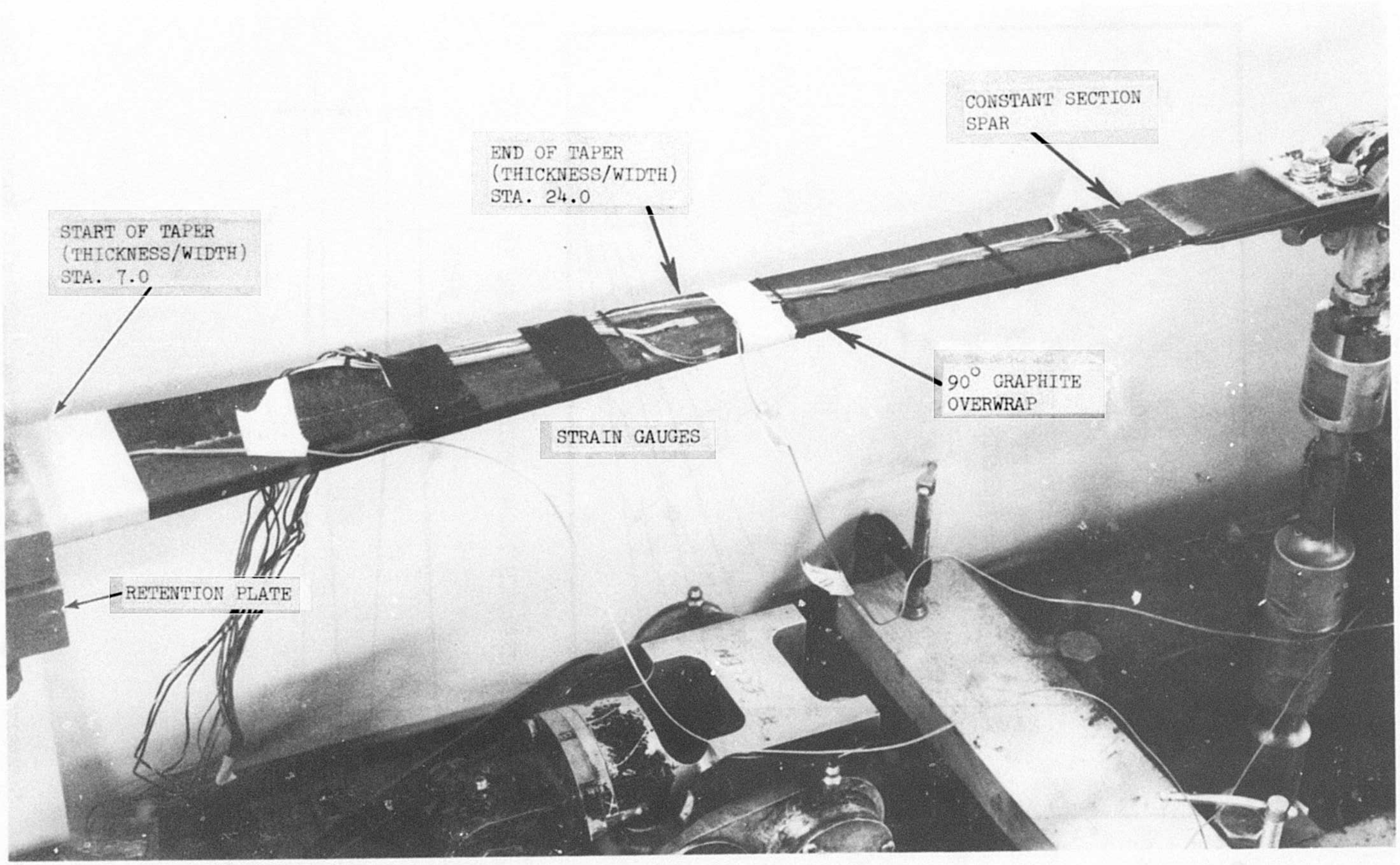


Figure 14. Subscale Fatigue Test of Concept II in Cantilever Beam Bending Facility.

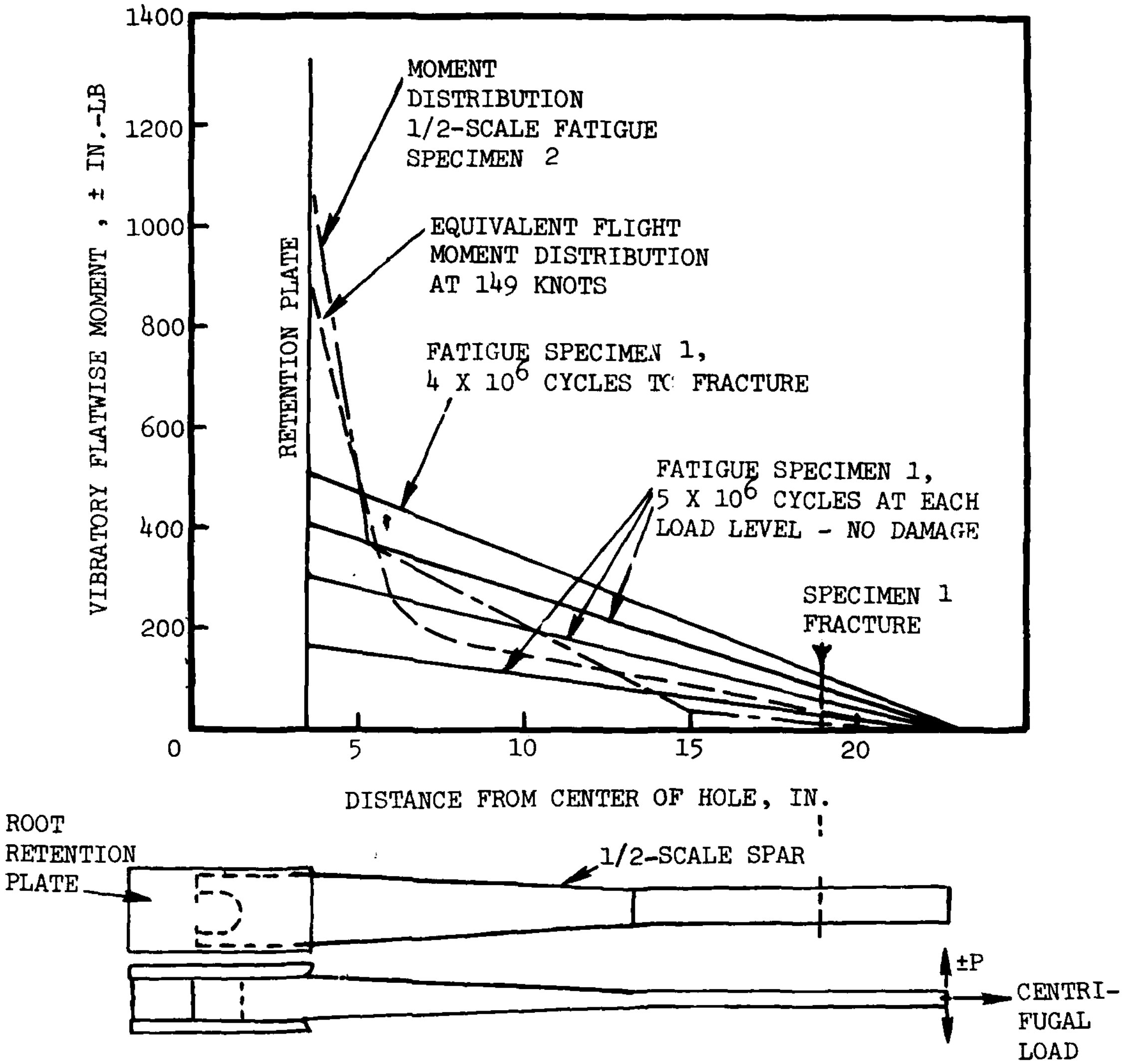


Figure 15. Summary of Fatigue Test Data for Subscale Concept II Spar.

Concept I - Full-Size Specimen

The full-size Concept I specimen was fabricated in accordance with the lay-up shown in Figure 4. Visual examination of the fabricated specimens revealed that the braided material (T300 graphite braided at $\pm 20^\circ/0^\circ$) manifested numerous weaving flaws not observed in the 8-foot sample previously found to be acceptable. Typical variations in the braid ranged from loose (open void) to tight weave with the 0° tows stitched-in (Figures 16 and 17). The braided material was used in order that experience would be gained in pultruding off-angle materials. Since subsequent machining would remove many of the braiding defects, it appeared that the observed flaws would have little or no effect on the axial strength of the spar.

The braided graphite material was easily incorporated into the pultrusion of the upper and lower root plates. The resultant pultrusion surface was rough with braided material exposed on the surface. Greater tensioning control was needed to be incorporated into the graphite braid. The loose graphite tows were the apparent cause of many of the surface imperfections and the strength variation observed in previous pultrusions.

Dimensional and visual inspection of the cured Concept I detail parts was performed prior to bonding. Overall, the spar pultrusion was of acceptable quality with only one isolated resin-rich area and one region of twisted graphite tow. An edgewise bow thought to be caused by shrinkage of the resin during the curing operation was observed. The bow in the as pultruded material measured 0.260 inch maximum arc height in the 10.5-foot length. A straightening fixture was made. The pultruded material was secured to the flat surface of the fixture and heated in an attempt to eliminate or minimize the bow. The pultruded material was secured in the fixture, heated to 350°F, held at temperature for 2 hours, and allowed to cool to room temperature. Subsequent inspection revealed that the bow or arc height was reduced from 0.260 to 0.060 inches. The 0.060-inch bow was considered acceptable at that time because the spar was to be reduced from 10.5 feet to 6 feet for the axial static test. Subsequent precured pultrusions required for Concept I were postcured to insure the required flatwise and edgewise flatness for bonding.

Static testing of the full-size Concept I specimen was performed in axial tension at room temperature. Failure occurred at 102,000 pounds, 80 percent of the predicted failure load. Separation was through the hub attachment hole at the root end region of the spar. Analysis disclosed the fiber volume to be 61 percent. Figure 18 shows the fractured specimen.

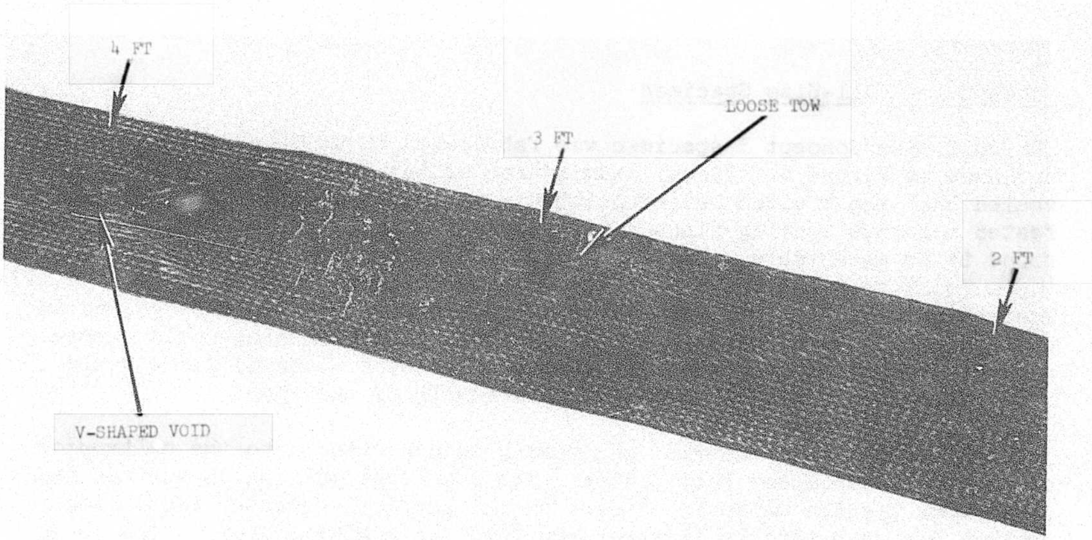


Figure 16. Typical Weaving Flaws of $\pm$ 20°/0° Braided Graphite.

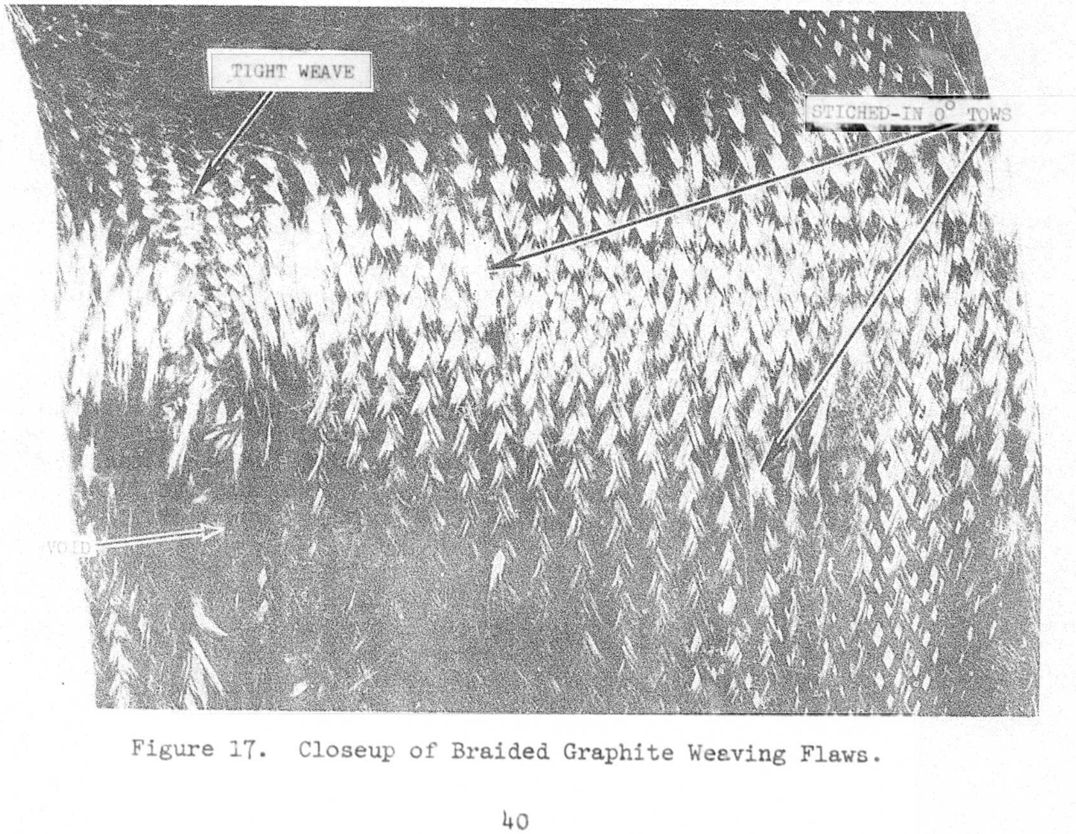


Figure 17. Closeup of Braided Graphite Weaving Flaws.

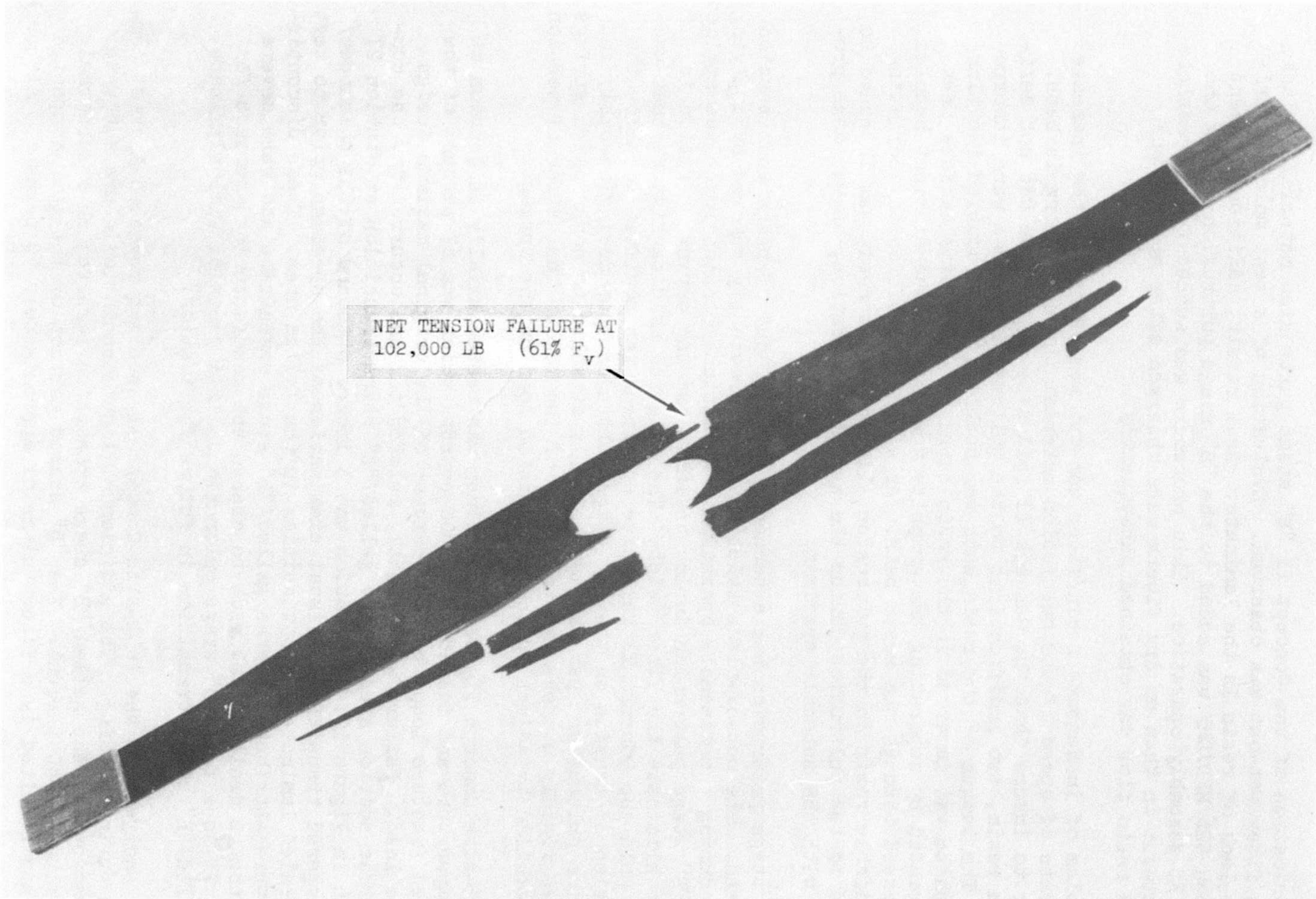


Figure 18. Concept I - Full-Size Static Specimen Showing Location of Fracture Through Hub Attachment Hole.

Concept II - Full-Size Specimen

Upon fabrication of the Concept II "B" stage pultrusion material, a lack of resin/fiber wet-out was observed. Evaluation of a test molding verified the lack of resin in the laminate. As a result, additional parent resin Epon 826/MPD/DMF was added to the "B" stage pultrusion during the Concept II assembly operation. This procedure was successful in complete fiber wet-out in that no dry fibers were observed after molding and adequate resin flow was obtained subsequently.

The problem of inadequate resin/fiber wet-out was caused by the increase in the rate of speed of the pultrusion material through the resin bath. In order to insure that the Concept II full-size pultrusion was not deficient in resin, two modifications to the pultrusion process were incorporated: The length of the resin bath was doubled, which doubled the time the graphite was immersed in the resin bath. The graphite surface area was increased by separating the graphite tows into three distinct bundles as it passed through the resin bath. As a backup position to increasing the available resin in the pultrusion, liquid parent resin was intended to be added to the pultrusion during the assembly operation, as was done previously with the subscale specimen.

The "B" stage pultrusion has a tendency to twist out of plane when tension is relaxed. The out-of-plane twist had been previously removed by applying tension during the assembly operation. A constant tension force was applied to the "B" stage pultrusion during assembly and the curing operation in order to eliminate the fiber twist. The existing molding fixture that was used to mold the Concept II full-size specimens was modified to allow the application of tension on the "B" stage pultruded spar during assembly and cure. The pultrusion spar was mechanically attached to compression springs that were rigidly attached to both ends of the tool. The degree of tension was controlled by adjusting the compression load on the springs.

The full-size Concept II static specimen was tested axially in tension at room temperature and failed at 88,000 pounds, which was 67 percent of the predicted fracture load, but 188 percent of the original maximum design ultimate load. Failure was directly related to, and occurred in, the constant cross-section area at the gelled/"B" stage transition at Station 27 as shown in Figure 19. Separation was 3 inches outboard of the thickness/width tapered transition. Visual examination of the specimen prior to test had revealed laminate discontinuities in the failed area. These discontinuities were attributed to the gelled/"B" stage transition and were severe enough that a decision was made to change the manufacturing approach for Concept II to a full "B" stage pultrusion. This decision will eliminate the gelled/"B" stage transition in future fabrication.

Failure analysis of the full-size Concept II specimen revealed lack of compaction during molding. The addition of liquid resin to insure adequate fiber wet-out in the gelled/"B" stage transition resulted in a subnormal fiber volume of 40 percent. The "B" staged portion of the spar compacted better and resulted in a fiber volume of approximately 50 percent. Although

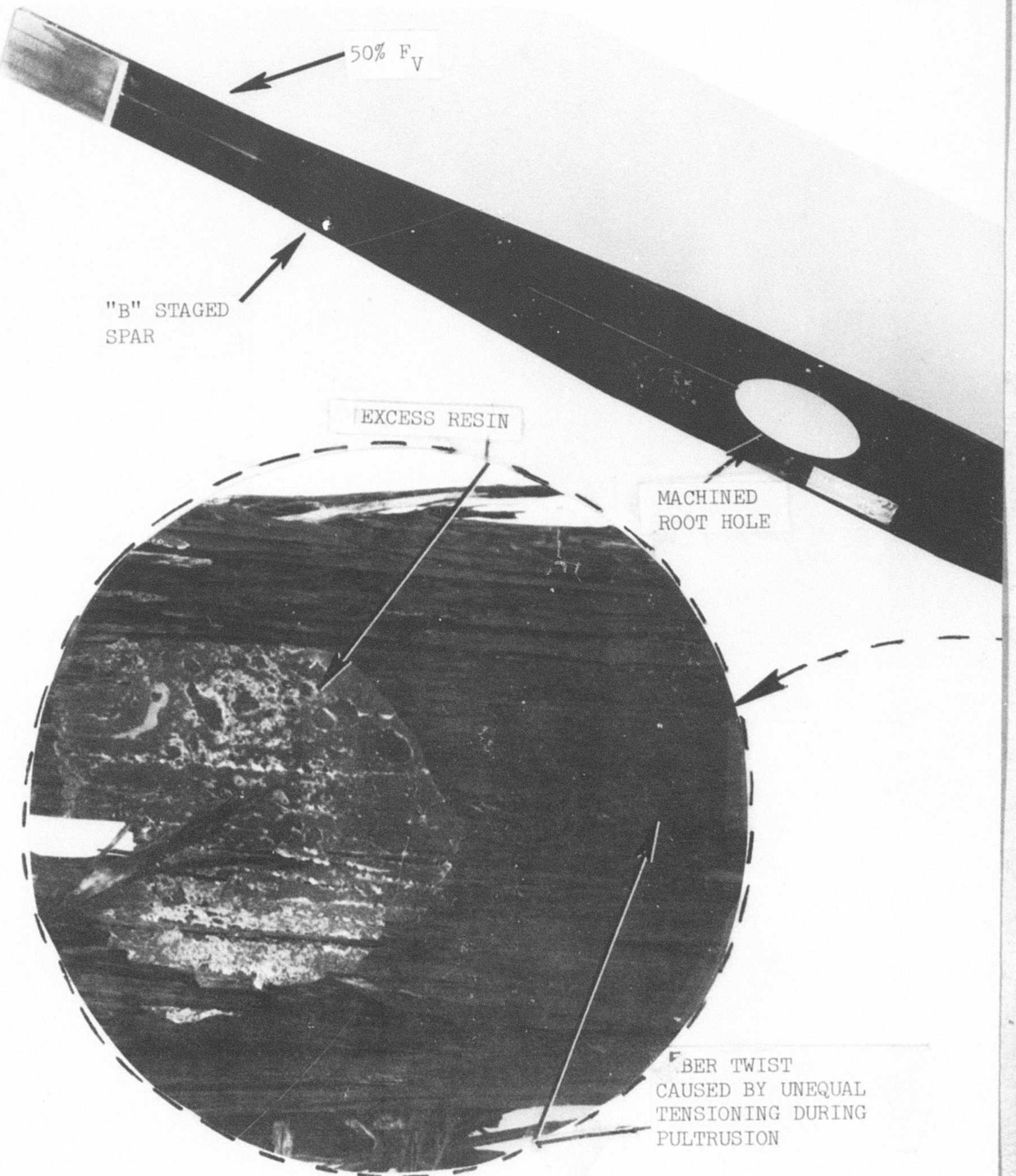
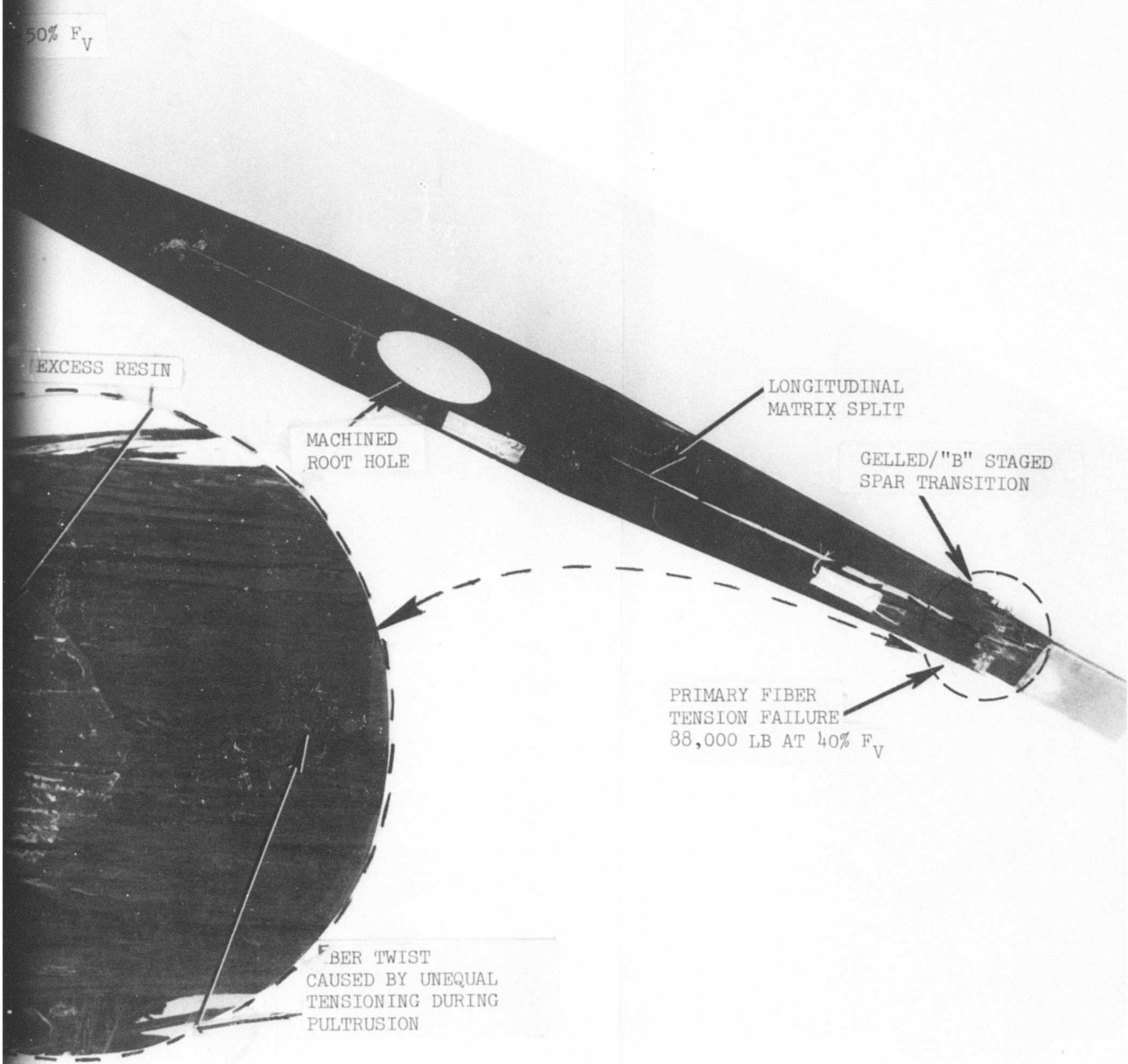


Figure 19. Concept II - Full-Size Static Specimen Showing Location of Fracture in Constant Cross-Section Area at the Gelled/"B" Staged Transition at Station 27.



II - Full-Size Static Specimen Showing Location of in Constant Cross-Section Area at the Gelled/"B" ransition at Station 27.

compaction of the spar was poor, the void contents were low, as shown in Figure 20. These results confirm the decision to modify the Concept II manufacturing approach to eliminate the gelled/"B" staged transition.

Based on the successful testing of Concept II subscale static specimens and the desire to demonstrate that gelled/"B" stage transition was the cause of the lower axial static strength experienced in the full-scale test, an additional subscale static specimen was made with the gelled/"B" staged transition and was compared to a specimen made with a "B" stage pultrusion.

Modified "B" stage pultruded spar material was received from the pultrusion vendor within 40 hours of shipment in excellent condition. The material had been packaged in dry ice for shipping to insure its partially cured condition. Upon receipt, the pultrusion was stored at -20°F for 4 days prior to assembly. The 6 days between pultrusion and assembly of the pultruded spar successfully demonstrated the stability of the "B" stage resin. As a result of the modifications made to the pultrusion process, the uniformity of the pultrusion "B" stage and resin/fiber wet-out was excellent. A Teflon separator sheet, which was inserted in the center of the pultrusion material during fabrication, aided in separating the graphite tows without causing fiber damage. The upper and lower plates and torpedo were laid up by hand using NARMCO 5209/AS prepreg as shown in Figure 21. The torpedo layup and transfer tool aided in positioning the torpedo into the tooling fixture by providing a hard point from which the "B" staged spar was properly shaped. Figures 22 and 23 show the assembly sequence. At the completion of the layup, the cover plate was positioned on the tooling fixture mold base. The thermocouples were installed and the assembly vacuum bagged. The assembly was subsequently autoclave cured at 260°F for 2 hours at 60 psi with full vacuum. Figure 24 shows the assembly prior to autoclave cure.

After autoclave cure, the completed spar was visually examined for defects. The gelled/"B" staged transition displayed poor fiber collimation and lack of fiber compaction. Thickness of the gelled/"B" staged transition ranged from 0.287 inches to 0.330 inches. Overall, the spar tooling mold did not close by approximately 0.040 inches, which resulted in a thicker spar. The inability to close the tooling mold also caused a lack of lateral compaction in the root hub region. The observed surface resin was excess parent resin Epon 826/MPD/DMF added during the spar assembly operation. The "B" stage transition area resulted in improved fiber collimation and compaction. A resin notch was formed in the pultrusion spar resulting from the bleeder cloth being pressed into the layup by autoclave pressure. This condition was eliminated in future spars by the use of a thin-gauge metal caul plate to fill in the gap.

Additional subscale axial testing was conducted to verify the mode of failure of the Concept II full-size specimens test. Five additional lengths of subscale pultrusion (1.4 inches wide x 0.148 inch thick by 24 inches long) were fabricated. Two specimens representing the gelled/"B" staged transition and two specimens with "B" staged pultrusion throughout were molded in a special female tooling that had been constructed for this purpose. The remaining length of pultruded material was held in abeyance

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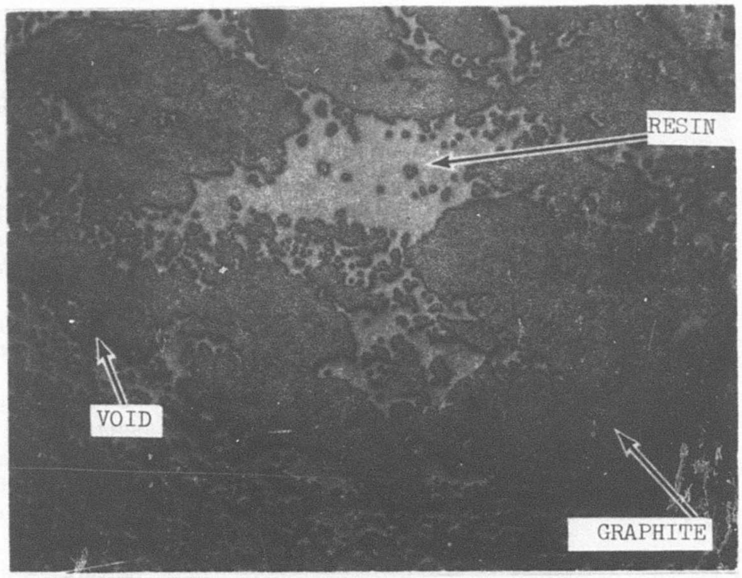
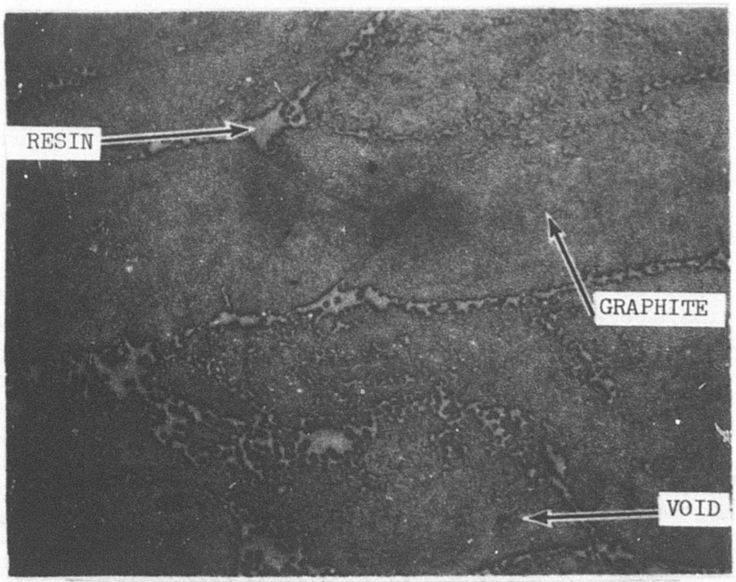


GELLED/"B" STAGE SPAR TRANSITION WITH 40% FIBER VOLUME



B STAGE SPAR AREA WITH OVER 50% FIBER VOLUME

Figure 20. Cross-Sectional Views of Concept II Full-Size Spar. (50X)

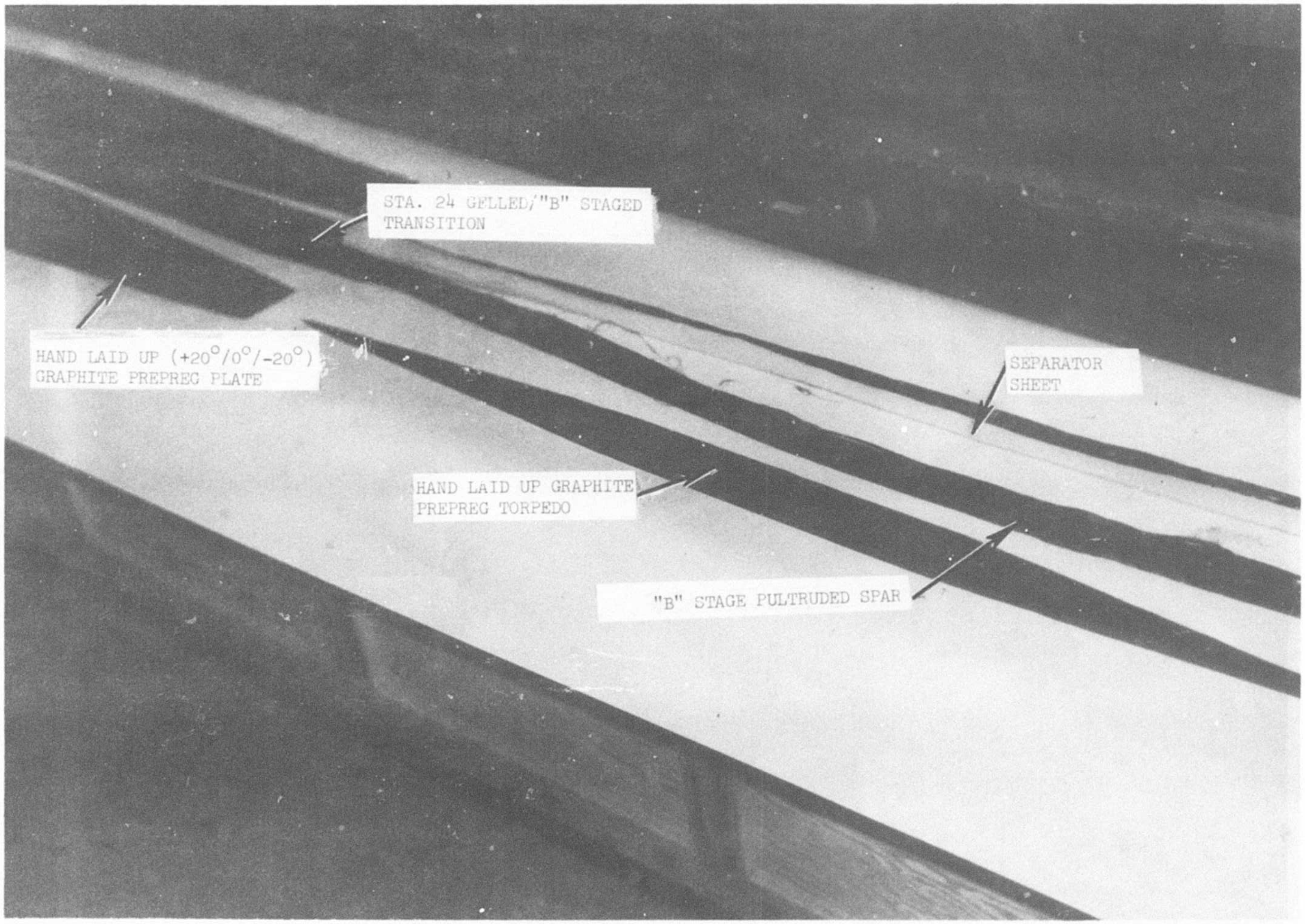


Figure 21. Concept II - Detail Parts.

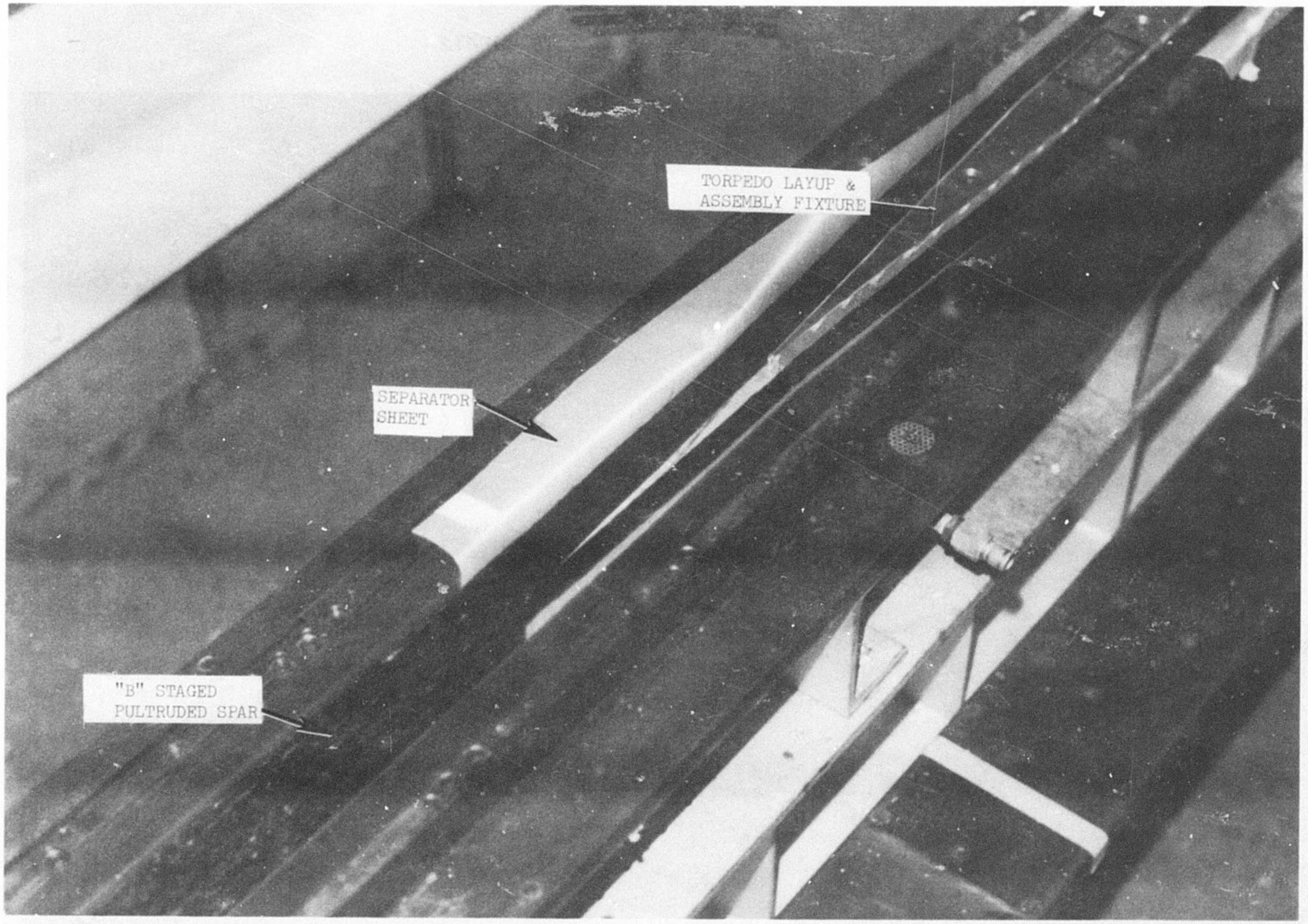


Figure 22. Concept II - Assembly Sequence, First Stage.

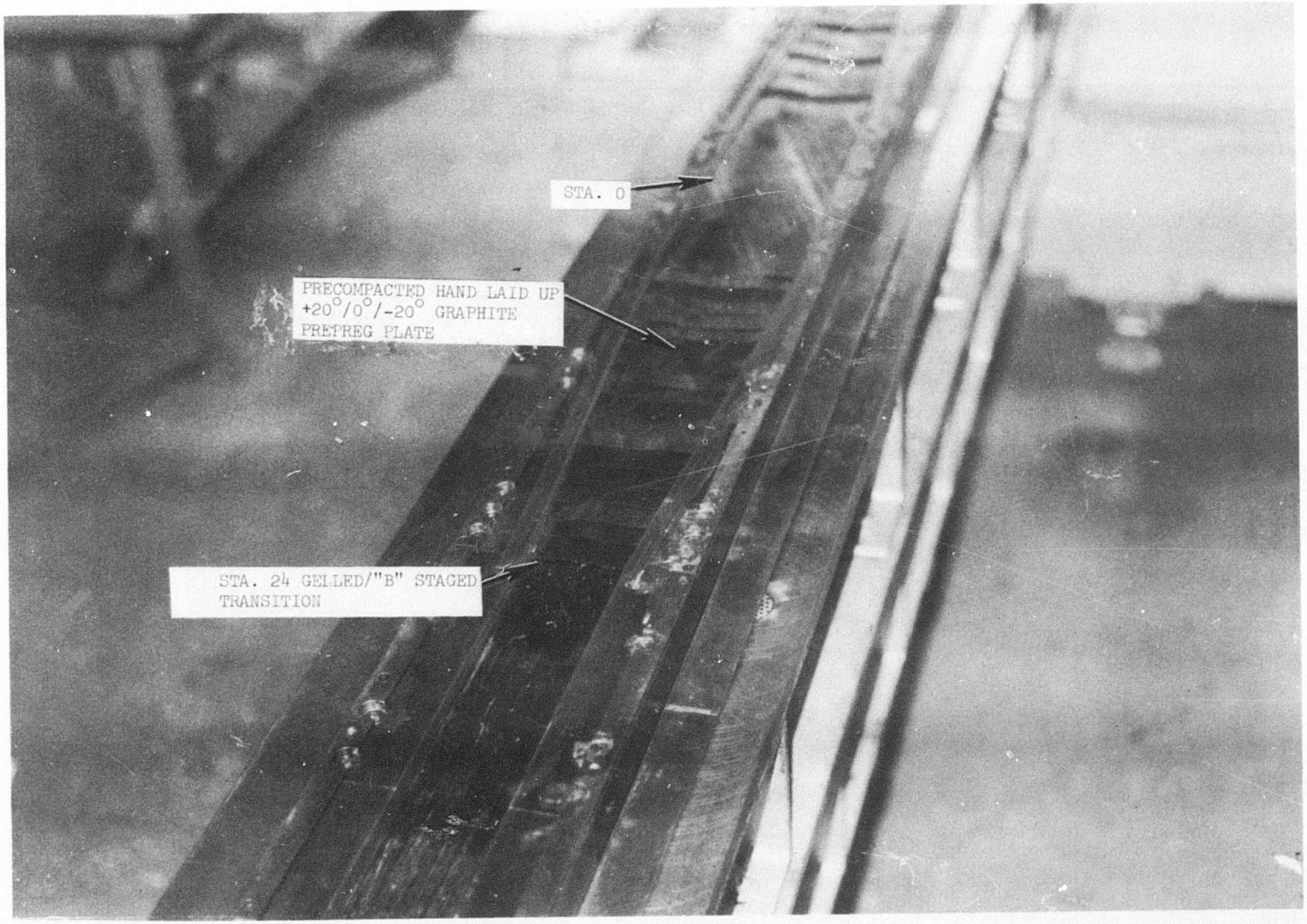


Figure 23. Concept II - Assembly Sequence, Second Stage.

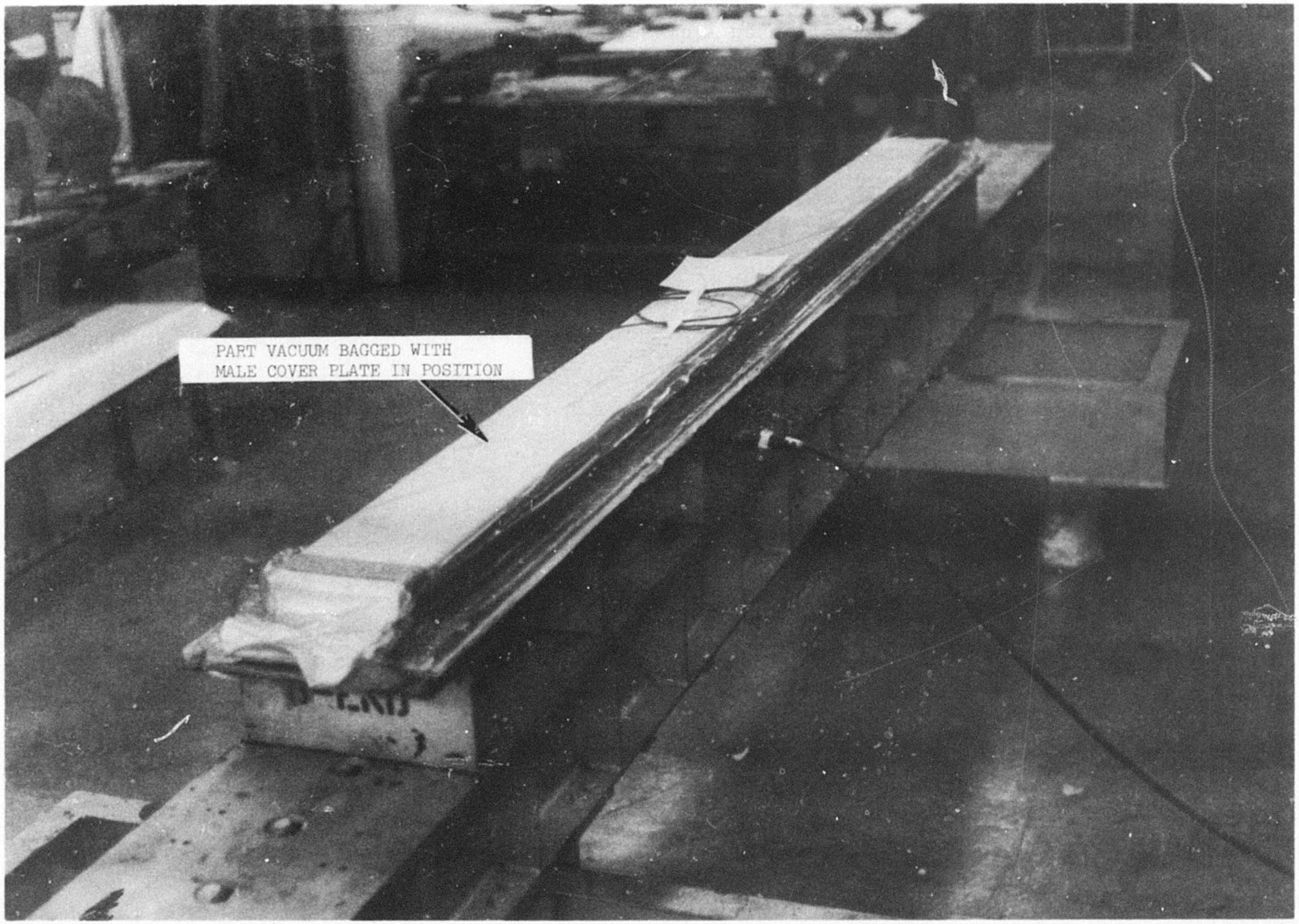


Figure 24. Concept II - Spar Assembly Prior to Autoclave Cure.

as a backup specimen. After specimen fabrication and installation of end grips, the four specimens were tested axially in tension at room temperature. The gelled/"B" staged transition specimens resulted in an average axial tension strength of 120,000 psi, which is 24 percent less than the 158,000 psi obtained with the "B" staged specimens without a gelled transition. Details of the results are depicted in Table 5. The maximum design ultimate strength of the spar is 130,000 pounds. This strength level is predicated on a 60-percent fiber volume. In an effort to obtain the 60-percent fiber volume, the gelled/"B" staged transition was eliminated and the mold pressure was increased to achieve the required spar thickness on subsequent pultrusion lengths. Figure 25 depicts the four specimens after testing.

TABLE 5. AXIAL SUBSCALE TEST RESULTS

Specimen Number	Method of Fabrication	Failure Load (psi)
1	"B" stage w/o transition	168,000
2	"B" stage w/o transition	148,000
3	"B" stage/gell transition	112,000
4	"B" stage/gell transition	128,000

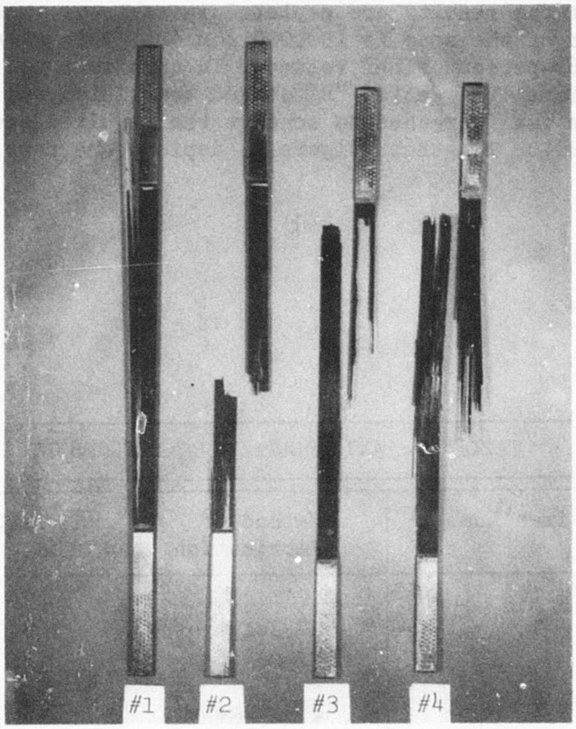


Figure 25. Axial Subscale Test Specimen After Testing.

Cost Analysis Concepts I and II

A cost analysis comparing Concept I and II spar pultrusion manufacturing approaches to the original conventional spar manufacturing design approach (prepreg/hand layup) was conducted. Material cost savings for Concepts I and II recurring cost savings were 47 percent and 62 percent respectively when compared to the original design conventional spar manufacturing cost. Table 6 provides a summary of the cost comparison.

TABLE 6. SUMMARY OF COST COMPARISON OF CONCEPTS I AND II WITH PROTOTYPE UTTAS SPAR

	Material Cost	Recurring Manufacturing (hr)	Percent Savings per Aircraft (2 spars)		Savings in Dollars for 1000 Aircraft	
			Material	Manhours	Material	Manhours ⓒ
Prototype UTTAS Spar	$1800 ⓐ	146	-	-	-	
Concept I (fully cured)	$1200 ⓑ	73	36%	47%	$676,800	$2,401,700
Concept II ("B" staged)	$1200 ⓑ	56	36%	62%	$676,800	$3,168,200

NOTES

ⓐ Prepreg cost $57/lb

ⓑ AS fiber cost $38/lb

ⓒ Manhour rate $35.00/hr

Final Concept Selection

As a result of the Phase I risk reduction testing, the Concept II "B" stage manufacturing process was selected for the Phase III spar fabrication. As cited previously, the Concept II design risk is low, but the manufacturing risks are high. However, these high manufacturing risks were identified during the risk reduction testing and were minimized. The critical processing variables had also been identified and were adequately controlled to insure that the Phase III pultruded spars had a fiber volume of 55 percent minimum. The Concept II subscale and full-size axial test results (adjusted for 60-percent fiber volume) are superior to Concept I, as shown in Table 7. In addition, Concept II has a lower cost potential than Concept I.

Following selection and approval of design Concept II and prior to the Phase III full-scale static and fatigue specimen fabrication, a detailed pultruded spar design, including the tip weight attachment, was completed (see Figure 51).

TABLE 7. COMPARISON OF CONCEPT I AND II AXIAL STATIC PROPERTIES

	Concept I	Concept II
Subscale Axial	82% of predicted failure load	122% and 95% of predicted failure load
Full-size Axial Tensile Strength	78% of predicted failure load	129% of predicted failure load

Additional Testing Following Concept Selection

Additional Concept II risk reduction testing was conducted in order to develop a cure cycle that would result in a "B" staged spar that was dimensionally accurate, with acceptable graphite fiber content, void content, and resin/fiber uniformity. The work included fabricating and evaluating a combination of small-scale and full-size spars to demonstrate process acceptability. The work was performed using two additional full-size "B" staged spars. The process variable investigation was conducted on 2-½-foot subcomponent specimens in a tool similar to the spar laminating mold. Final demonstration of the process risk reduction was conducted using a full-size "B" staged spar mold that was used to fabricate the Phase III spars. The first "B" staged pultrusion exhibited low resin flow and dryness, which resulted in moldings of poor quality with no flow or material compaction. The material was stored at 0°F for 4 weeks before being molded. This, coupled with delays in shipping and subsequent evaporation of dry ice during shipment, caused the "B" pultrusion to advance beyond the usable stage. Because of the cited situations, changes were made in the pultrusion process to minimize the amount of heat applied to the resin mixture during the process. The decrease in applied heat afforded increased resin flow and compaction of the laminate during the molding operation. In addition, more resin was allowed to remain in the pultrusion by increasing the opening in the resin squeeze-out bushings.

The remaining two "B" stage pultruded spars for the Concept II process risk reduction were unacceptable for use due to lack of resin/fiber uniformity, fiber twisting, and, most important, advancement of the pultrusion "B" stage beyond the usable state due to prolonged shipping time. This situation necessitated a new course of action. The revised approach entailed performing additional risk reduction work on the first full-size spar. Verification of the process was intended to be achieved on the second spar. These results are discussed in Phase III.

PHASE II - SMALL SPECIMEN STATIC AND FATIGUE TEST

General

This phase of the program included static and fatigue testing of unidirectional pultruded laminates. The testing was performed at various temperatures to verify that the material selected for pultrusion met the requirements of the prepreg material specification in effect at that time and those of the original YUH-60A prepreg spar design. The results of the testing indicated that, with sufficient postcure treatment, the pultruded material met or exceeded all of the original prepreg design requirements except for minor deviation in static strength at 250°F. The 250°F level is well above the maximum aircraft design requirement of 165°F. By the time the production prepreg spar was redesigned because of increased load requirements and environmental characteristics, the material specification for prepreg was upgraded and higher design properties were used. The higher design requirements are discussed in detail in Phase V.

Details

Pultruded laminate material used in the small specimen testing was cured at 400°F for 1 hour prior to testing. Axial and fatigue properties were determined from laminates 0.072 inches thick while flexure and interlaminar shear strength properties were determined from 0.10-inch-thick laminates.

Initial elevated temperature (160°F and 250°F) testing for flexure and interlaminar shear strength resulted in strength dropoffs that were greater than anticipated. However, room temperature properties were satisfactory. The remaining specimens were given an additional postcure of 1 hour at 200°F plus 2 hours at 350°F in an effort to improve the material's elevated temperature strength retention. This effort proved to be successful. The elevated temperature strength retention was improved by approximately 40 percent. The resulting properties were within the allowable strength reductions of the graphite prepreg specification except for minor deviations at 250°F, which is in excess of the maximum aircraft design requirement of + 165°F. Table 8 lists the detailed test results while Figures 26, 27, and 28 show the small specimen static data compared to the original prepreg requirements. The lack of matrix/reinforcement uniformity as illustrated in Figure 29 is typical of the pultrusions evaluated and is reflected in the scatter observed in the small specimen test results. The initial laminates received for axial test had numerous surface discontinuities and defects.

Fatigue testing of small specimens was accomplished in combined steady tension/vibratory torsion and combined steady tension/vibratory bending. As in the case of the elevated temperature tests, the lack of sufficient postcure had a serious effect on the fatigue properties. Both the torsion and bending specimens without the additional postcure were tested and found to be below the standard graphite prepreg materials evaluated previously. By postcuring the remaining specimens, as discussed earlier, and testing

TABLE 8. SMALL SPECIMEN STATIC TEST RESULTS (a)

	* Graphite-Epoxy Prepreg Requirements				EPON 826/AS - Pultrusion (Average of 3 to 5 Specimens)							
					Postcured (b)				Non Postcured (c)			
	-65°F	RT	160°F	250°F	-65°F	RT	160°F	250°F	65°F	RT	160°F	250°F
Flexural Strength, ksi	(d) (.95RT)	200 -	(e) (.7RT)	(f) (.65RT)	-	272	213 (.78RT)	130 (.48RT)	224 (1.1RT)	212	155 (.73RT)	73.5 (.35RT)
Flexural Modulus, psi x 10^6	(g) (.95-1.05RT)	16to 18	(d) (.95RT)	(f) (.65RT)	-	17.1	15.8 (.92RT)	13.4 (.78RT)	16.7 (1.RT)	16.7	13.8 (.83RT)	8.5 (.51RT)
Interlaminar Shear Strength, psi	(d) (.95RT)	12,000 -	(e) (.7RT)	(f) (.65RT)	-	13590	11800 (.87RT)	7,600 (.56RT)	18,200 (1.4RT)	14100	9,400 (.67RT)	6,000 (.43RT)
Tensile Strength, ksi	No Rqmt	No Rqmt	No Rqmt	No Rqmt	192.0	188.3	189.0	(h)	-	210	-	-
Tensile Modulus, psi x 10^6	No Rqmt	No Rqmt	No Rqmt	No Rqmt	18.0	17.8	17.9	18.1	-	19.3	-	-
Transverse Tensile Strain, μ in./in.	No Rqmt	4,000	No Rqmt	No Rqmt	-	-	-	-		3800		

<u>NOTES</u>:

(a) Based on 60% fiber volume.

(b) Cured 1 hour at 400°F followed by postcure of 1 hour at 200°F + 2 hours at 350°F.

(c) Cured 1 hour at 400°F.

(d) 95% of actual room temperature value.

(e) 70% of actual room temperature value.

(f) 65% of actual room temperature value.

(g) 95-105% of actual room temperature value.

(h) Specimens failed in alignment pin or fiberglass gripper - invalid test.

* Original specification values as existed during design of the prototype prepreg YUH-60A tail rotor spar.

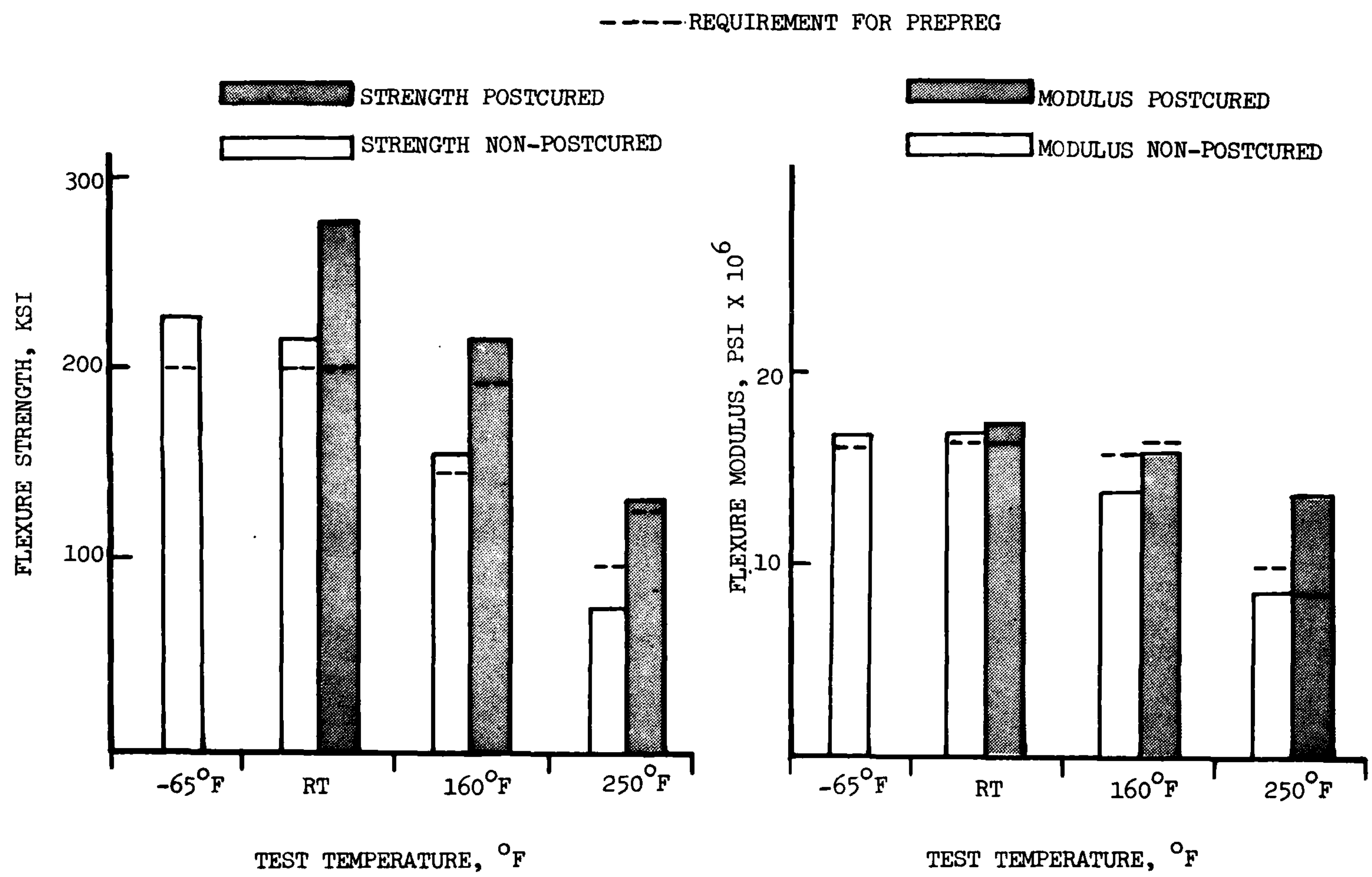


Figure 26. Small Specimen Flexure Strength and Modulus at Several Temperature Levels for Epon 826/AS Pultrusion.

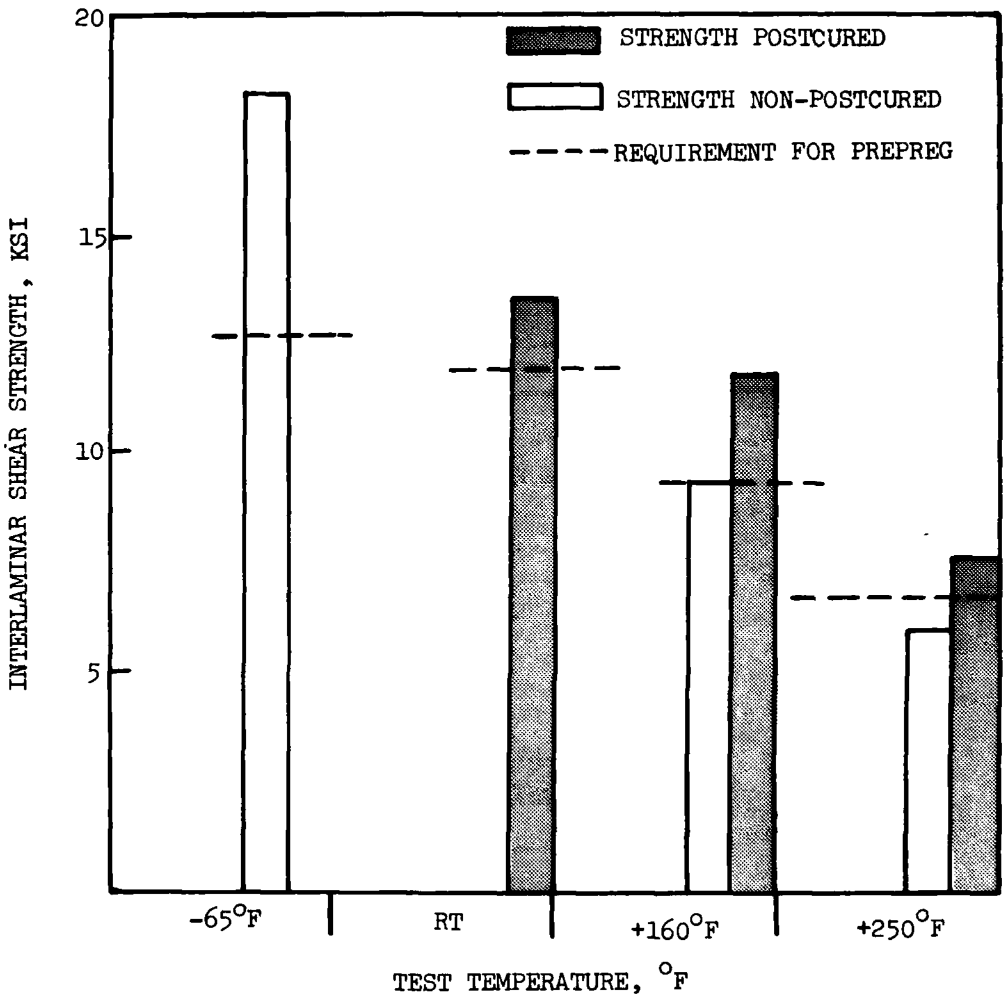


Figure 27. Small Specimen Interlaminar Shear Strength at Several Temperature Levels for Epon 826/AS Pultrusion.

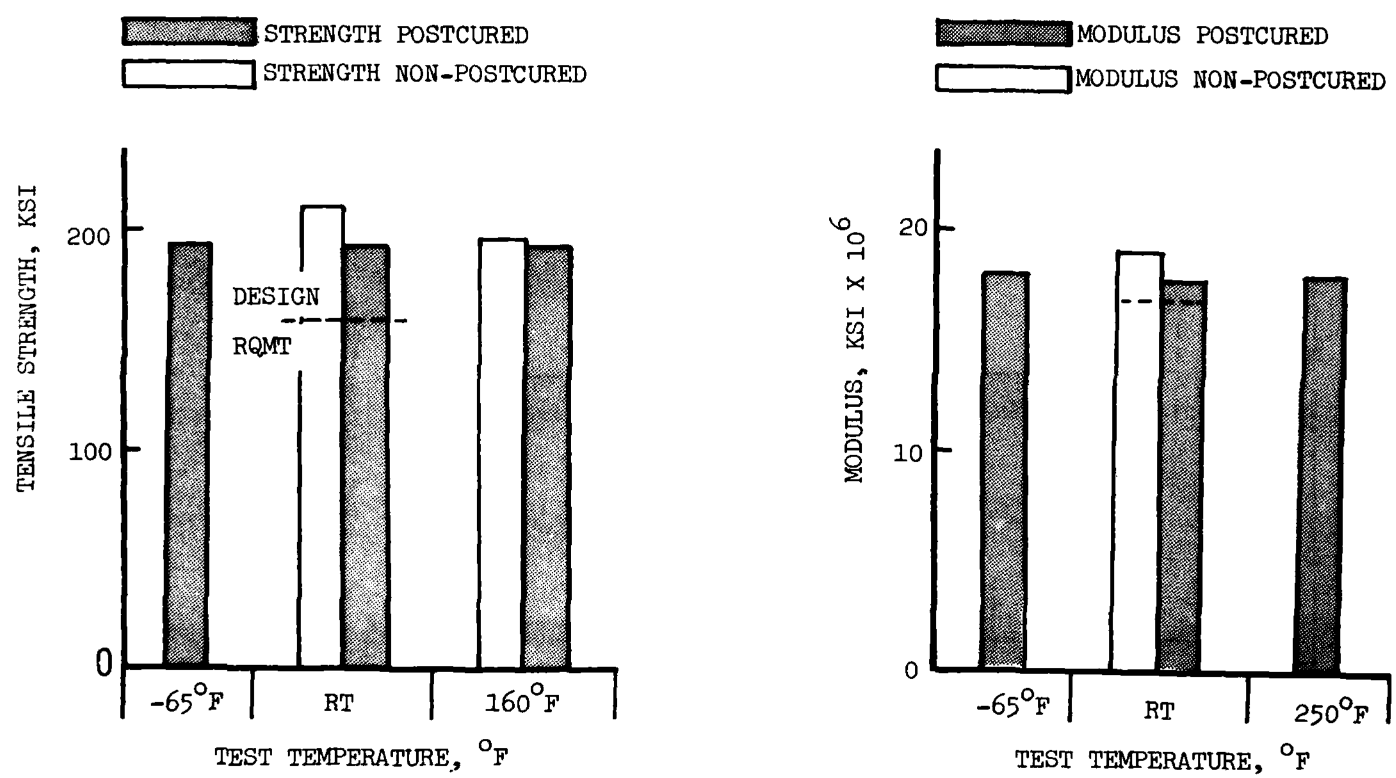


Figure 28. Small Specimen Tensile Strength and Modulus at Several Temperature Levels for Epon 826/AS Pultrusion.

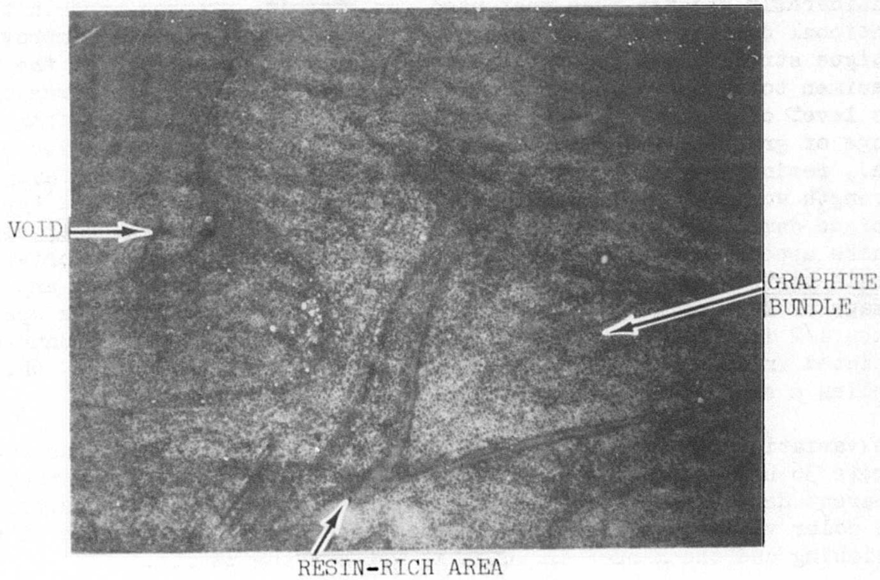


Figure 29. Structure of Typical Pultruded Static Specimen. (50X)

individual specimens at various stress/strain levels, they were found to compare favorably to the standard materials.

Fatigue damage was determined by the degree of modulus reduction recorded after 10^7 cycles at the various stress/strain levels as noted in Tables 9 and 10. Figures 30 and 31 show the small specimen fatigue results to be comparable to the range of graphite prepreg evaluated. When plotted on a Goodman diagram, the axial fatigue curve for unidirectional pultrusion is considerably greater than that used for graphite prepreg used in the conventional design, as illustrated in Figures 32 and 33. The improvement in fatigue strength due to postcure is evident and comparison of the postcure specimen to standard graphite is favorable. The current pultrusion with its level of quality produced results in a fatigue strength within the range of graphite materials tested. By improving the pultrusion quality, i.e., resin/fiber uniformity, it is felt that the pultrusion fatigue strength would also be improved. Figures 34 and 35 illustrate typical fatigue damage induced by torsion and bending loadings respectively. The cracks appear to initiate at the specimen edge and propagate laterally within the resin. Figure 36 shows a torsion specimen without any noted damage or loss of modulus. Photomicrographs of representative specimens taken 1/2 inch away from the initial point of damage show no damage, as depicted in Figure 37. Specimen 6 recorded 47 percent damage, which implies a slow crack propagation rate.

The variation in color within the individual graphite bundle as noted in Figure 36 has been observed in many of the photomicrographs without any apparent detrimental effect on the strength of the graphite pultrusion. The color variations may be due to differences in the graphite fiber finishing and the manner in which it wet-out the matrix.

TABLE 9. 826/AS TORSIONAL FATIGUE TEST RESULTS

Specimen Number	Fiber Volume (percent)	Centrifugal Stress (psi)	Vibratory Shear Strain ($\pm$ μ in./in.)	Vibratory Shear Stress ($\pm$ psi)	Initial Torsional Modulus-(G) x 10^6 psi	Modulus Reduction at 10^7 Cycles (percent)
C-2	58.0	9,400	9,000	7,100	0.79	40.0
C-4	59.5	9,400	7,000	5,700	0.81	40.0
C-3	58.0	9,400	4,000	3,200	0.79	0
C-1 (a)	58.0	9,400	5,500	4,300	0.78	0
C-3 (a) (b)	56.0	9,400	7,000	5,200	0.74	0
C-3 (a) (b)	56.0	9,400	9,000	6,700	0.74	23.0

NOTES:

(a) Material postcured 1 hr @ 200°F and 2 hr @ 350°F.

(b) Same specimen retested at the higher strain/(stress) level indicated.

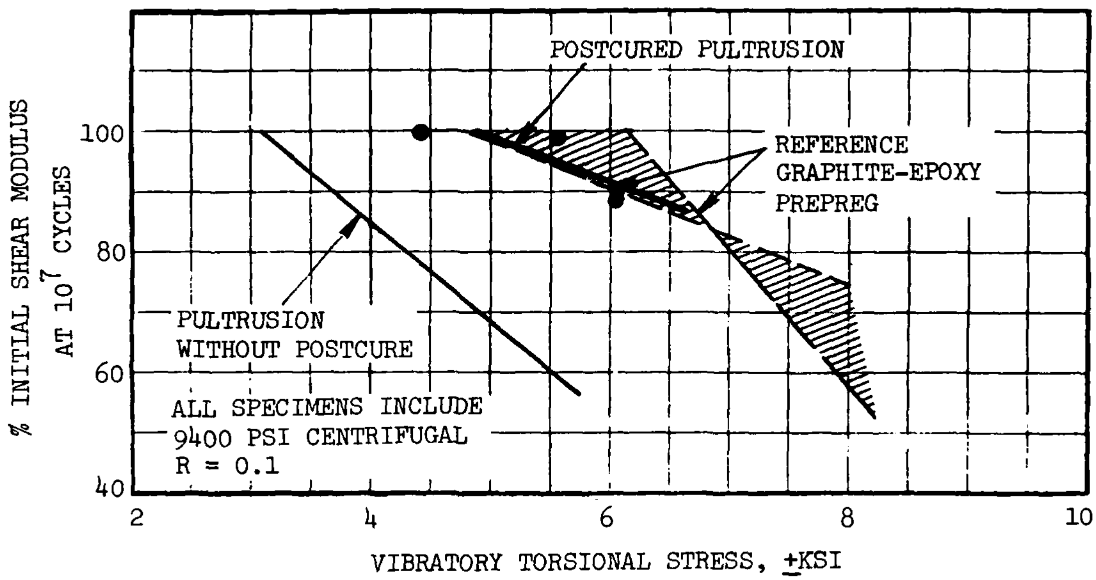
TABLE 10. 826/AS FLATWISE BENDING FATIGUE TEST RESULTS

Specimen Number	Fiber Volume (percent)	Centrifugal Stress (psi)	Flatwise Bending Strain ($\pm\mu$ in./in.)	Flatwise Bending Stress ($\pm$ psi)	Initial Flexural Modulus (E_B) x 10^6 psi	Modulus Reduction @ 10^7 Cycles (percent)
C-7	58.0	9,400	2,350	40,800	17.4	0
C-5	57.5	9,400	5,000	84,500	16.9	82.0
C-8	59.5	9,400	2,740	49,100	17.9	6.0
C-6 (a)	58.0	9,400	3,800	64,600	17.0	47.0
C-7 (a) (b)	58.0	9,400	3,150	48,800	15.5	0
C-7 (a) (b)	58.0	9,400	4,630	71,800	15.5	5.0
C-7 (a) (b)	58.0	9,400	5,280	81,900	15.5	17.0

NOTES:

(a) Material Postcured 1 hr @ 200°F and 2 hr @ 350°F.

(b) Same specimen retested at the higher strain/(stress) level as indicated.



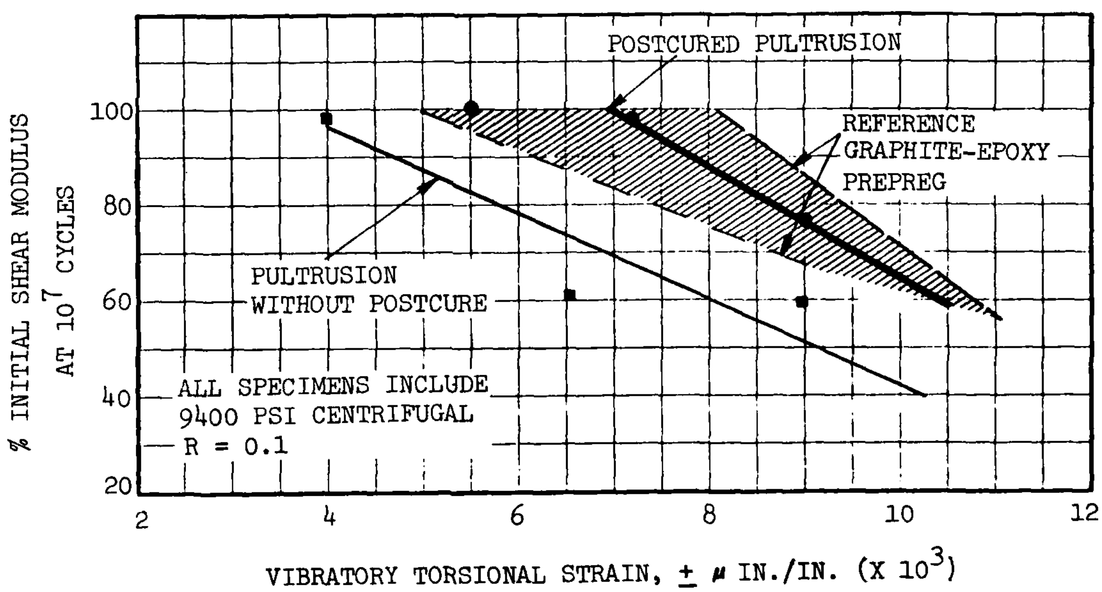


Figure 30. Small-Scale Torsional Stress and Strain Fatigue Data of Pultrusion and Prepreg Materials.

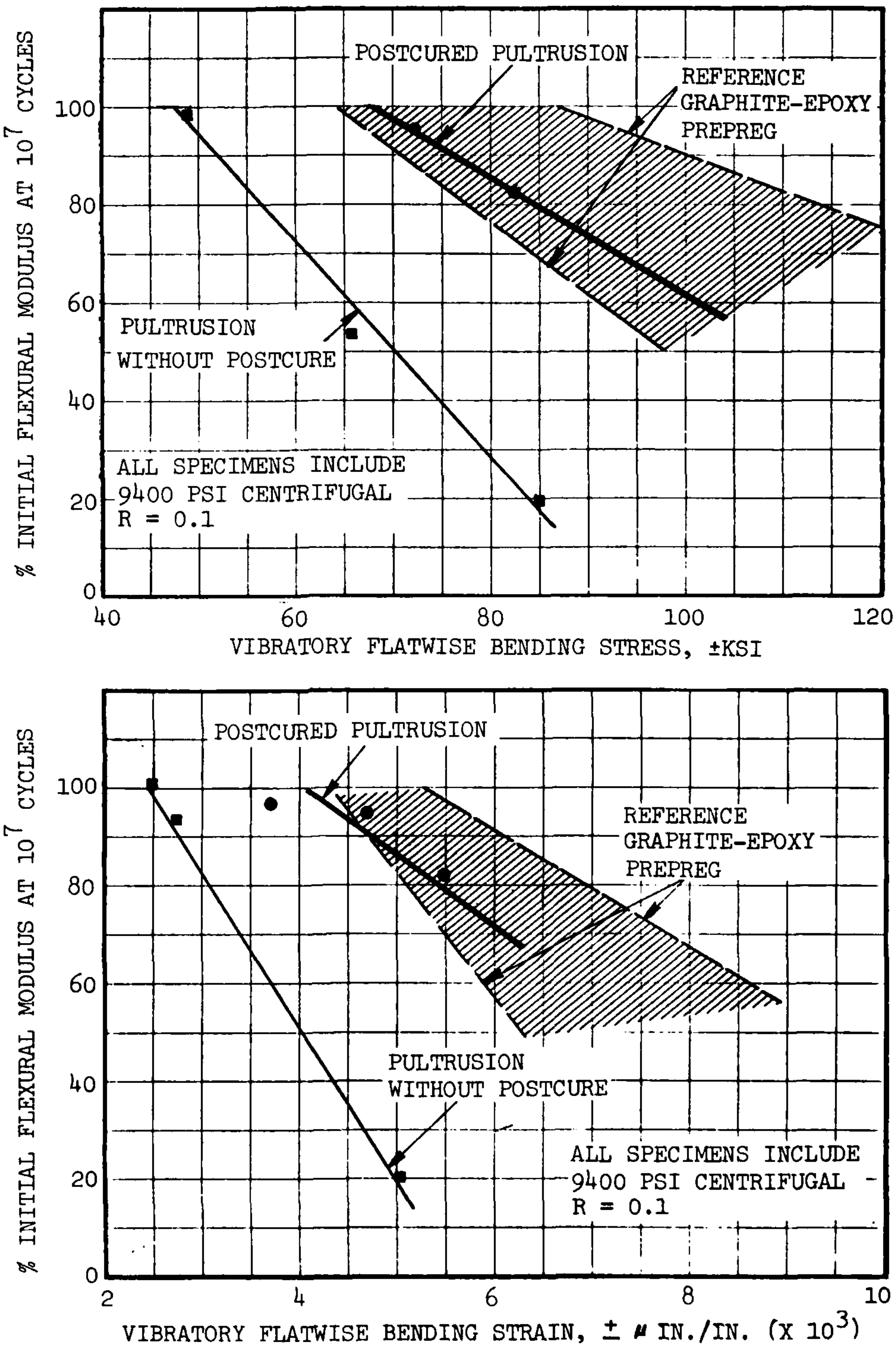


Figure 31. Small-Scale Flatwise Bending Stress and Strain Fatigue Data of Pultrusion and Prepreg Materials.

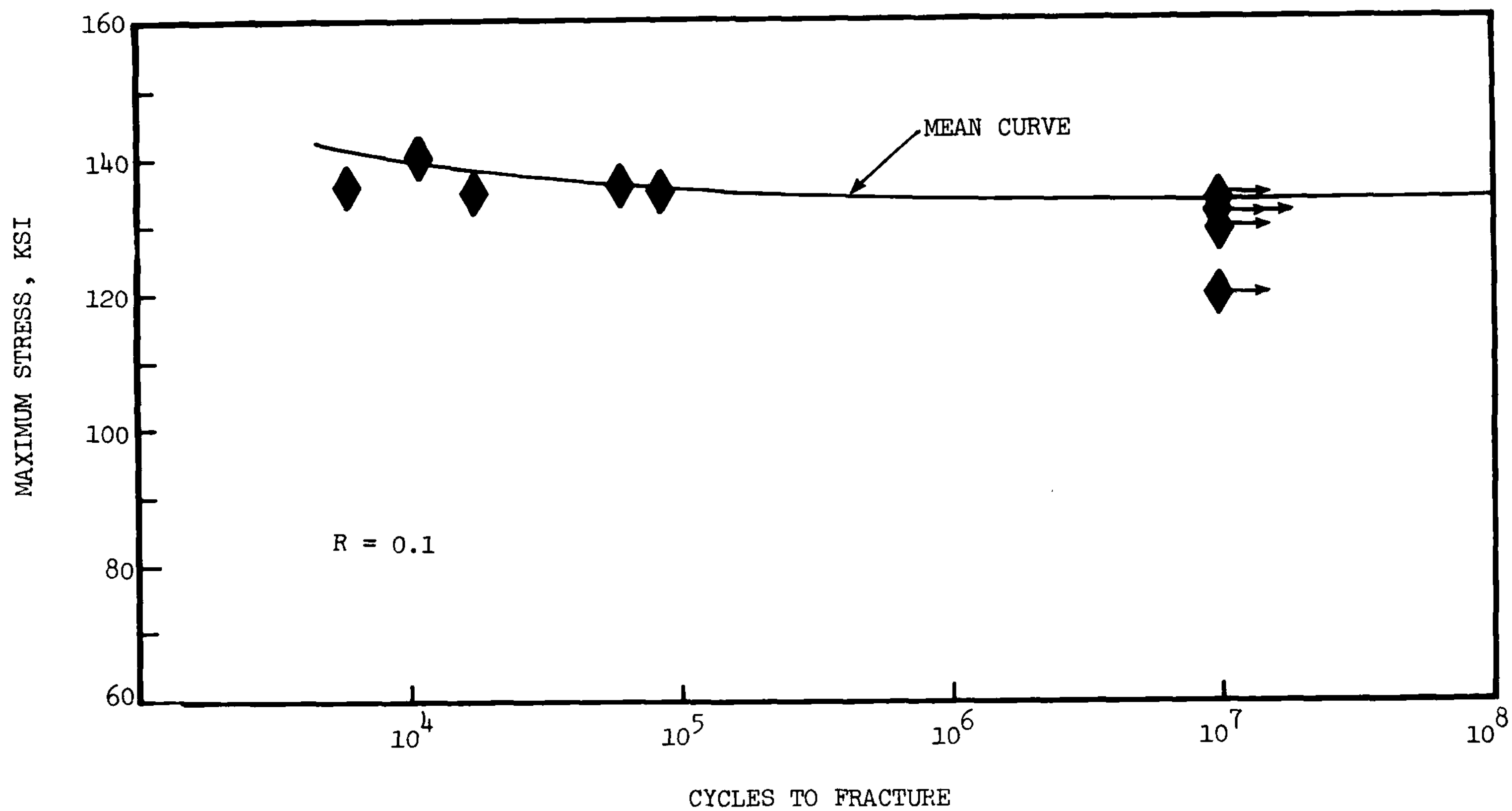


Figure 32. 826/AS Graphite Material Axial Fatigue Properties.

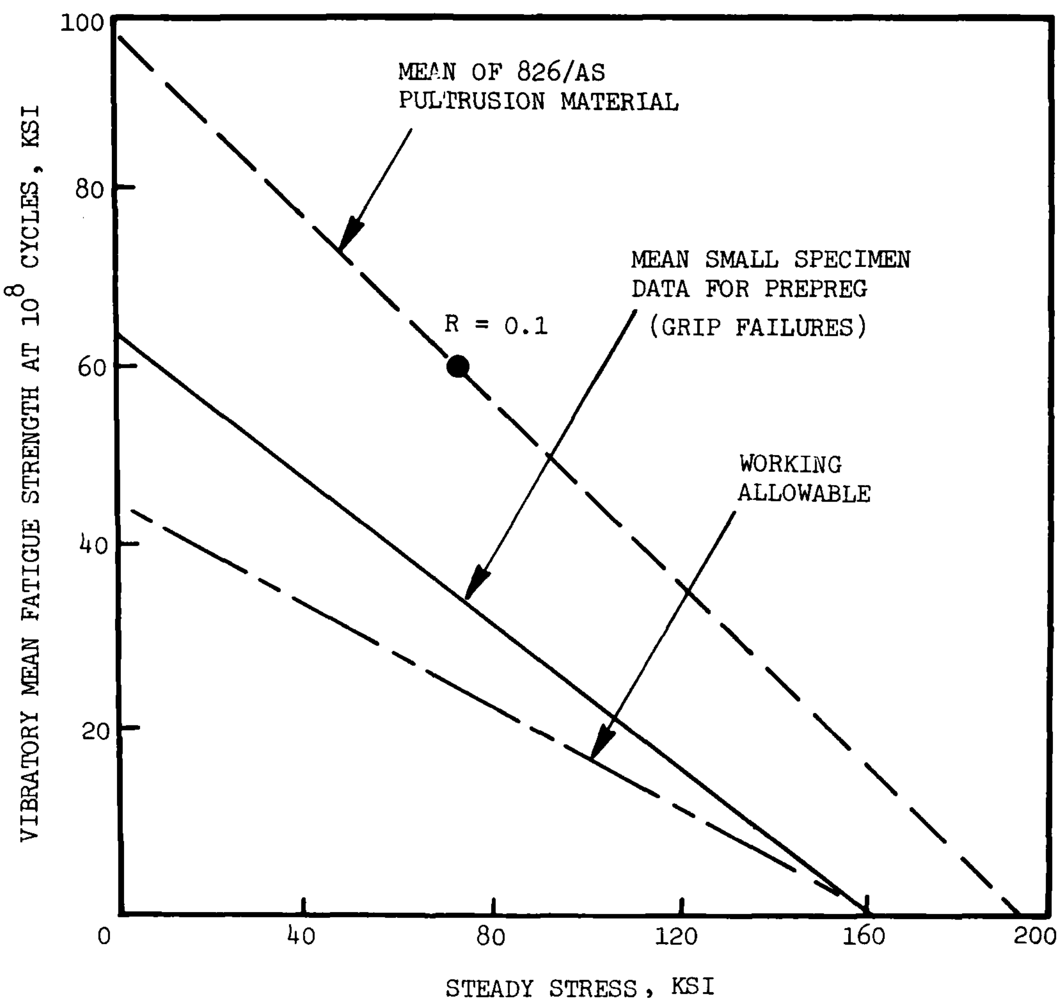


Figure 33. Comparison of Fatigue Properties for Prepreg and Pultruded Materials Used in Design Analysis.

Figure 34. Typical Fatigue Damage Induced by Torsion. (Specimen 2) (50X)

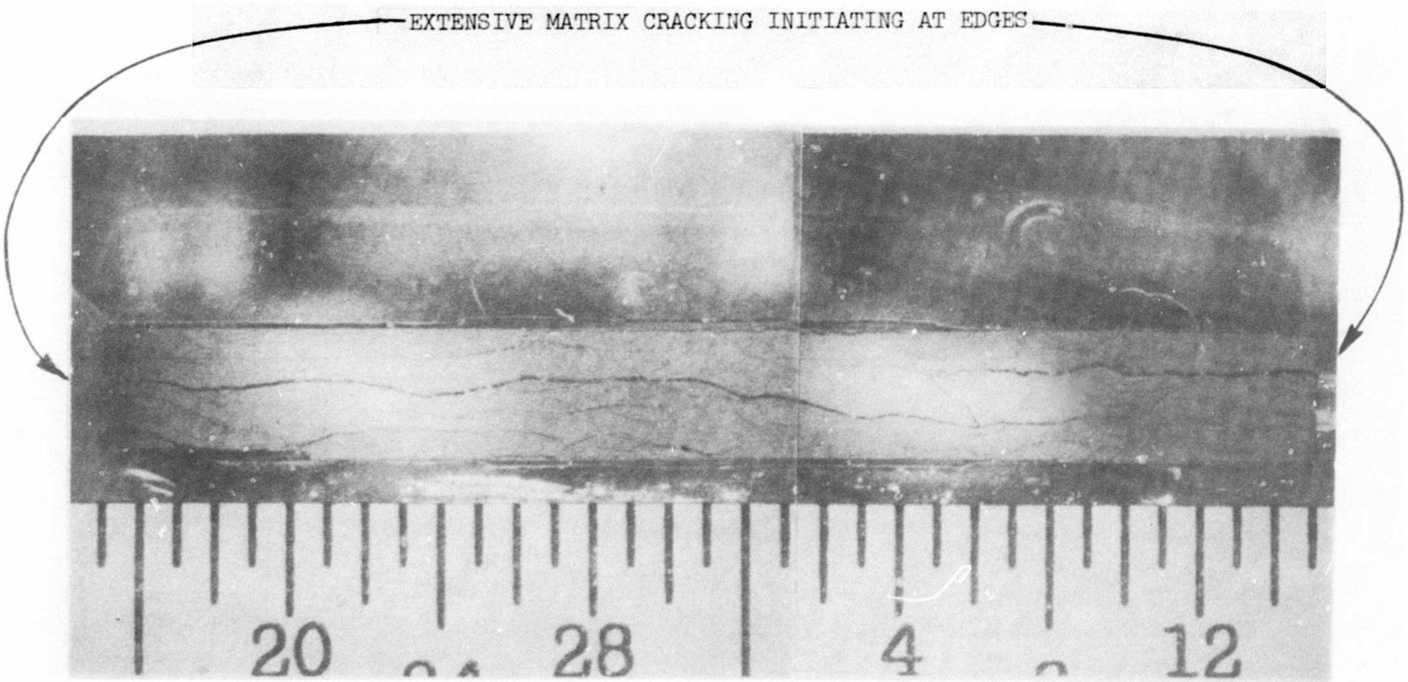


Figure 35. Typical Fatigue Damage Induced by Bending. (Specimen 6) (4X)

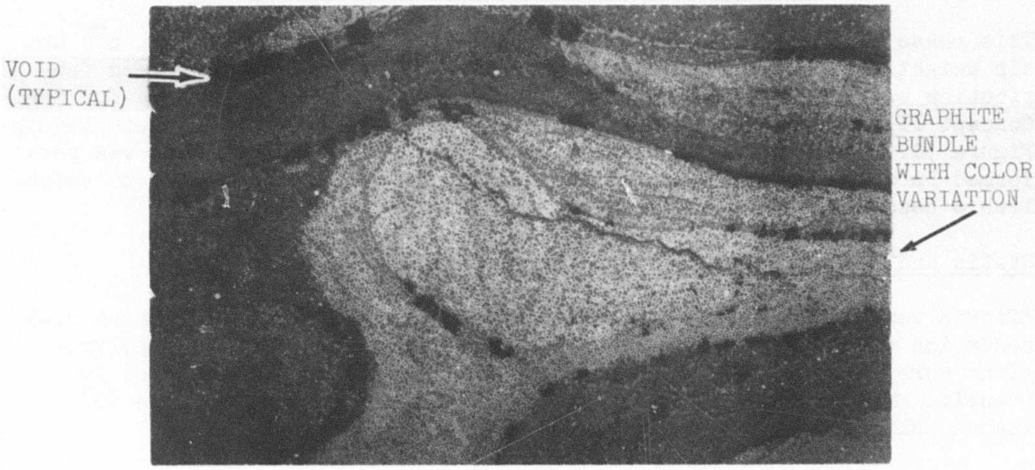


Figure 36. Torsion Fatigue Specimen Without Damage and Variation in Color. (Specimen 1) (50X)

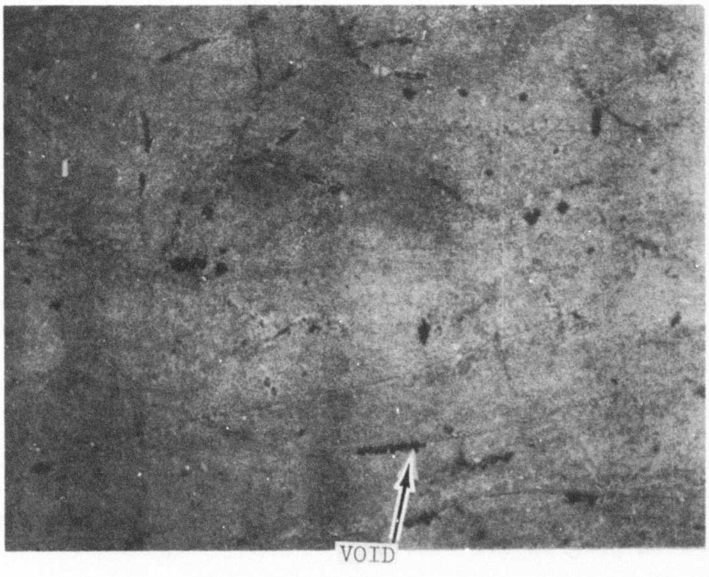


Figure 37. Typical Specimen Structure. (50X)

PHASE III - FULL-SIZE STATIC AND FATIGUE SPECIMEN FABRICATION AND NONDESTRUCTIVE INSPECTION

This phase of the program involved fabrication of full-scale root end and tip weight attachment pultruded component test specimens. Specimen fabrication was accomplished in general accordance with the drawings for the Concept II root end design and tip weight attachment design as detailed in Figure 51. Nondestructive inspection of the full-size specimens was performed in order to characterize the quality of the specimens and to establish a baseline.

Static and Fatigue Spar Specimen Fabrication

Efforts were generated to complete the additional Concept II process risk reduction work described previously in Phase I. The first four pultrusions were received in two shipments. Both shipments were delayed in transit. The delay caused the dry ice to evaporate and allow the "B" staged pultrusions to advance beyond use.

Specimens 1 and 2, 30 inches in length, representing the tail rotor spar from Station 0 to Station 30, were molded from the second shipment of pultrusion material. Attempts to fabricate specimens from this material resulted in components with extensive voids, lack of compaction, fiber tows not coated with resin, fiber twisting, and lack of resin flow during the autoclave molding operation. Figures 38 and 39 illustrate the defects and dimensional variations observed in the specimens. These defects were caused by resin advancement during transit, pultrusion pulling rate and die temperature, and the technique used in stringing the graphite tows.

Corrective action was taken in the subsequent "B" stage pultrusions to eliminate those defects. The corrective action included reducing the spar shipping time from 5 days to 31 hours with an increase in the amount of dry ice present in the container during shipping so that at least 75 percent of the original dry ice was present on arrival from the pultrusion vendor. Other corrective action relating to the process techniques entailed lowering the speed by which the pultrusion material was drawn through the pultrusion die. This greatly improved the resin fiber wet-out and allowed more complete resin coating. The height of the resin squeeze-out bushings was increased in order to increase the resin loading in the pultrusion.

The autoclave pressure used to mold the spar and prepreg plates was increased to 165 psi (including 15 psi of vacuum) in order to assist in obtaining closure of the molding tool.

Specimens 3 through 7 were fabricated incorporating the described corrective actions with progressive successes.

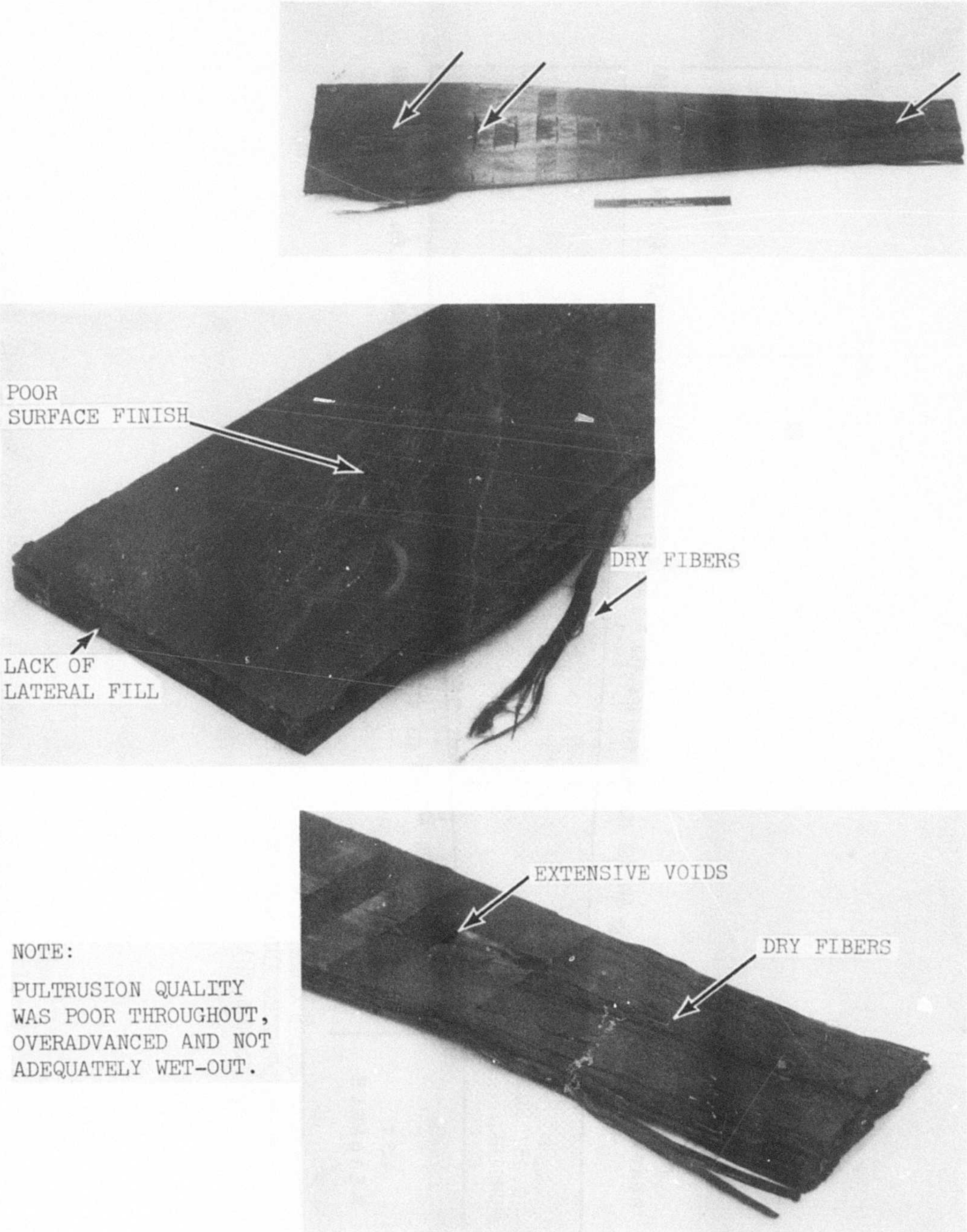


Figure 38. Appearance of 30-inch Spar Specimen, S/N 2.
(Defects depicted by arrows)

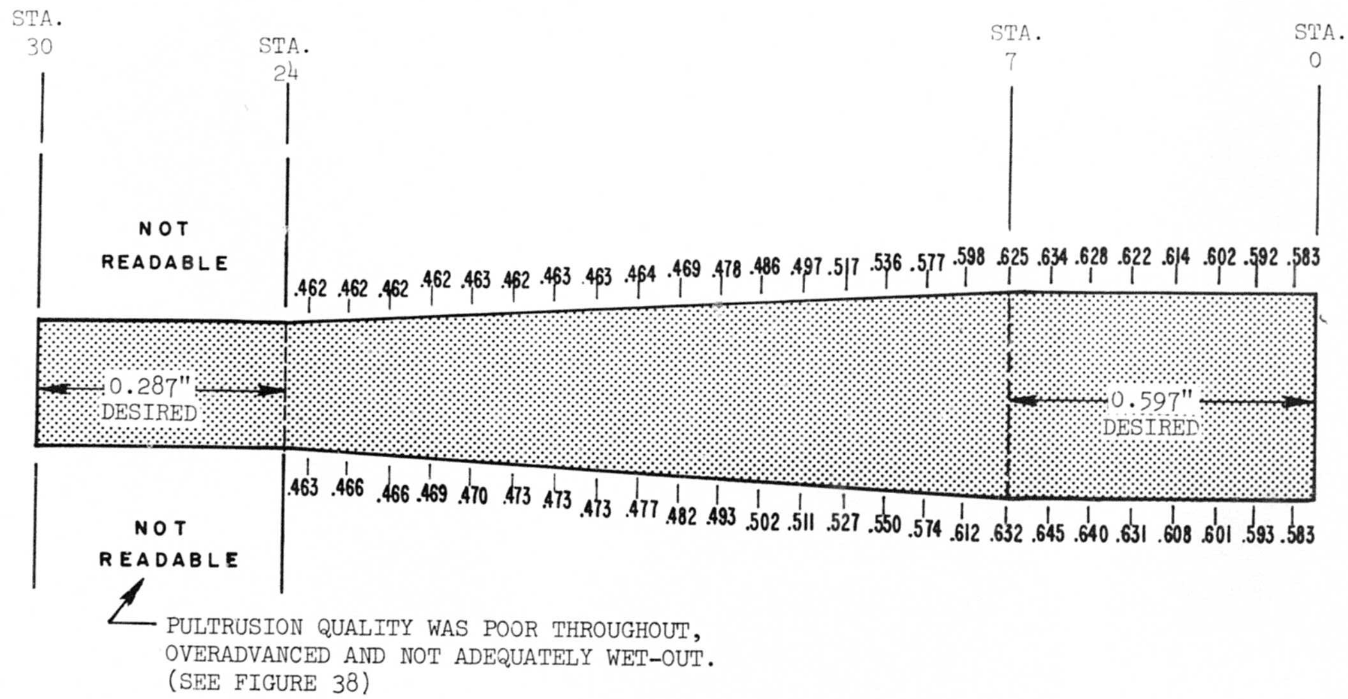


Figure 39. Thickness Variations in 30-inch Spar Specimen, S/N 2.

Specimen 3, 30 inches in length, representing the spar from Station 0 to Station 30, was fabricated. The specimen exhibited good quality in the constant thickness pultrusion area; however, voids were evident in the prepreg root end buildup regions. These voids were attributed to the undersize fit of the prepreg torpedo. Figures 40 and 41 show the lack of fill and voids caused by the undersize torpedo in the center section, and the dimensional variations in the spar.

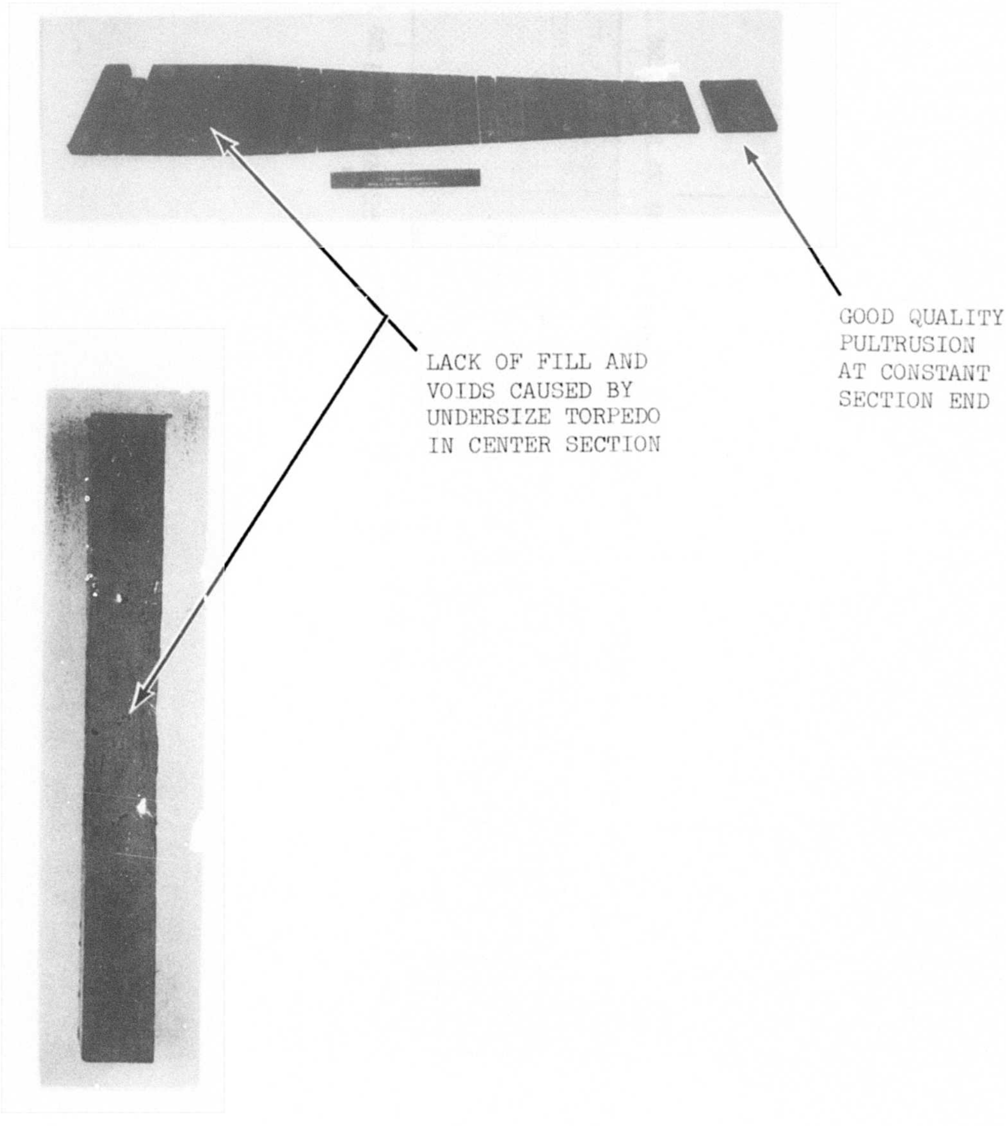


Figure 40. Appearance of 30-inch Spar Specimen, S/N 3.

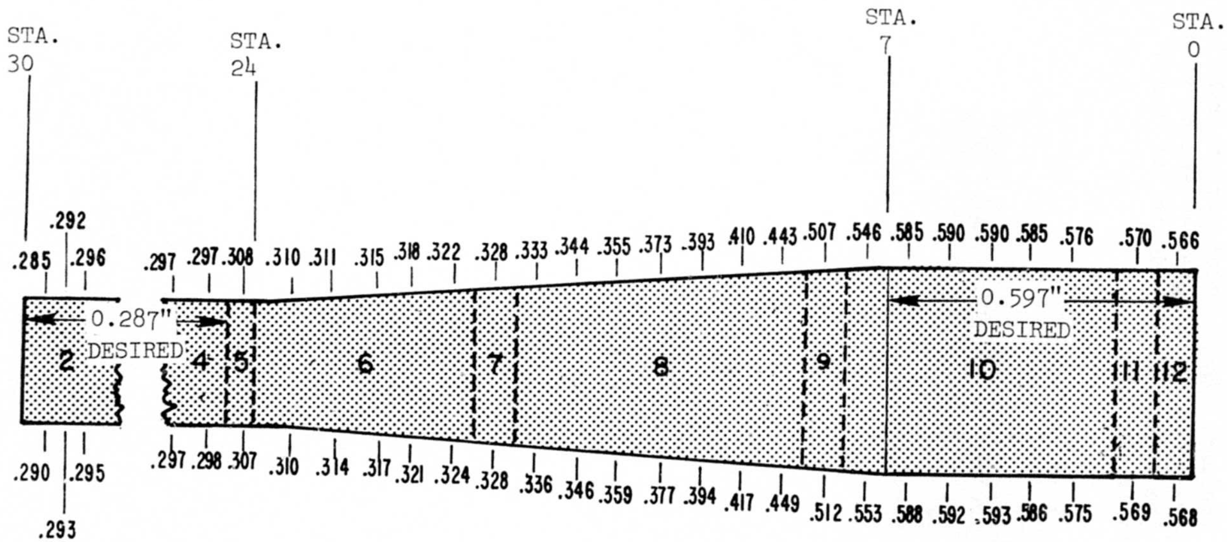


Figure 41. Thickness Variations in 30-inch Spar Specimen, S/N 3.

Specimen 4, 30 inches in length, representing the spar from Station 0 to Station 30, was fabricated using an improved prepreg torpedo layup and pultrusion material of poor quality. The section of pultrusion used was from the start of the pultrusion run and was intermittently coated with resin. The quality of the cured specimen was excellent, but the root end region of the specimen was approximately 0.020 inch oversize. Figures 42 and 43 depict the voids and dry fibers at the end of the specimen, and the dimensional variations in the spar.

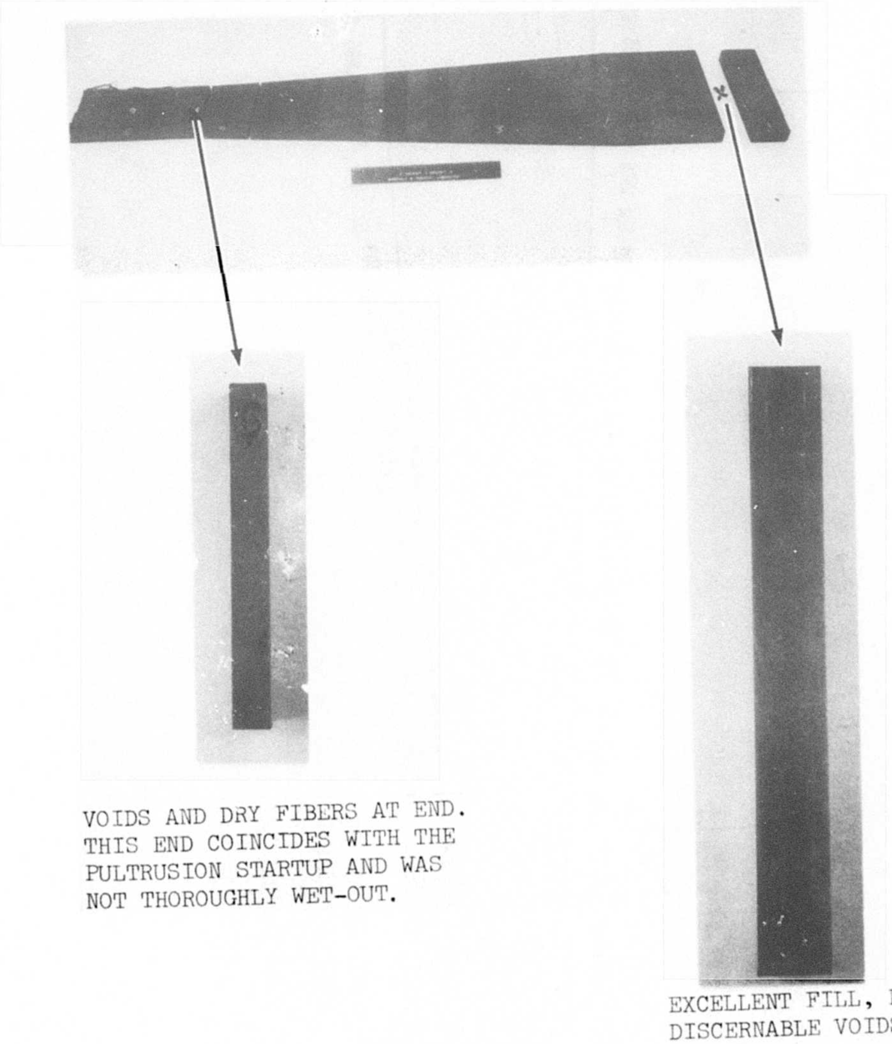


Figure 42. Appearance of 30-inch Spar Specimen, S/N 4.

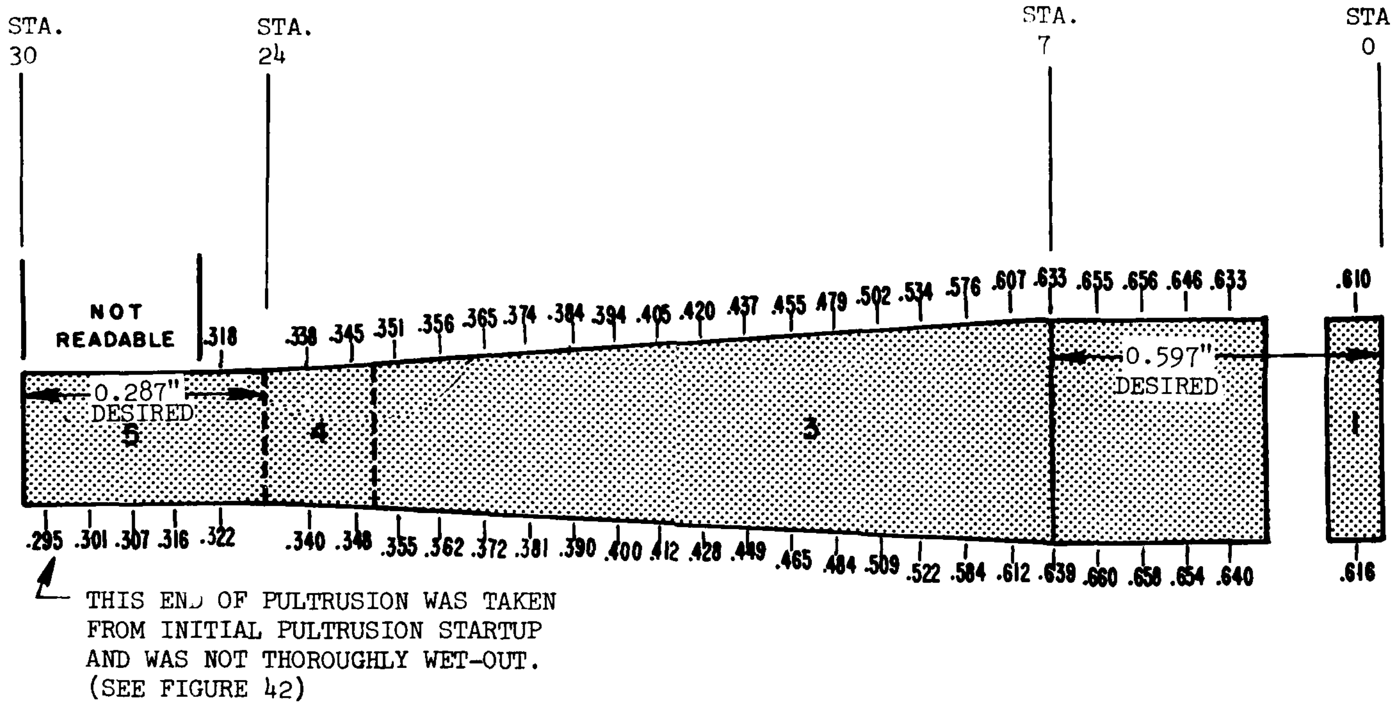
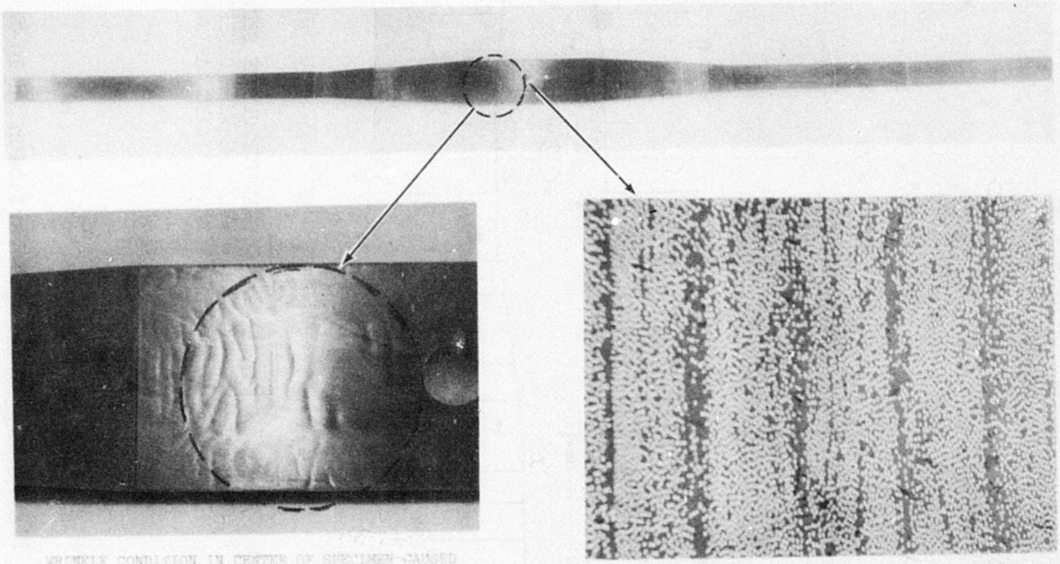


Figure 43. Thickness Variations in 30-inch Spar Specimen, S/N 4.

Specimen 5 produced a full-size specimen of excellent quality. The specimen was 120 inches long, representing the spar from Station + 60 to Station - 60. The surface finish, resin flow, and compaction were all of the highest caliber. No evidence of voids, dry fiber, or lack of fill was detected. Wrinkles were noted at the root end region. It was determined that the prepreg plates' ply length did not match the taper in the tool. This mismatch condition caused the prepreg material to move, causing wrinkles. Figures 44 and 45 show the full-size spar and its dimensional variation.



WRINKLE CONDITION IN CENTER OF SPECIMEN CAUSED BY INCORRECT LENGTH PLATE LAMINATES.

100X PHOTOMICROGRAPH ILLUSTRATING TYPICAL CONDITION AND LACK OF VOIDS IN CENTER PLUG AREA.

Figure 44. Appearance of Full-Size 10-foot Spar, S/N 5.

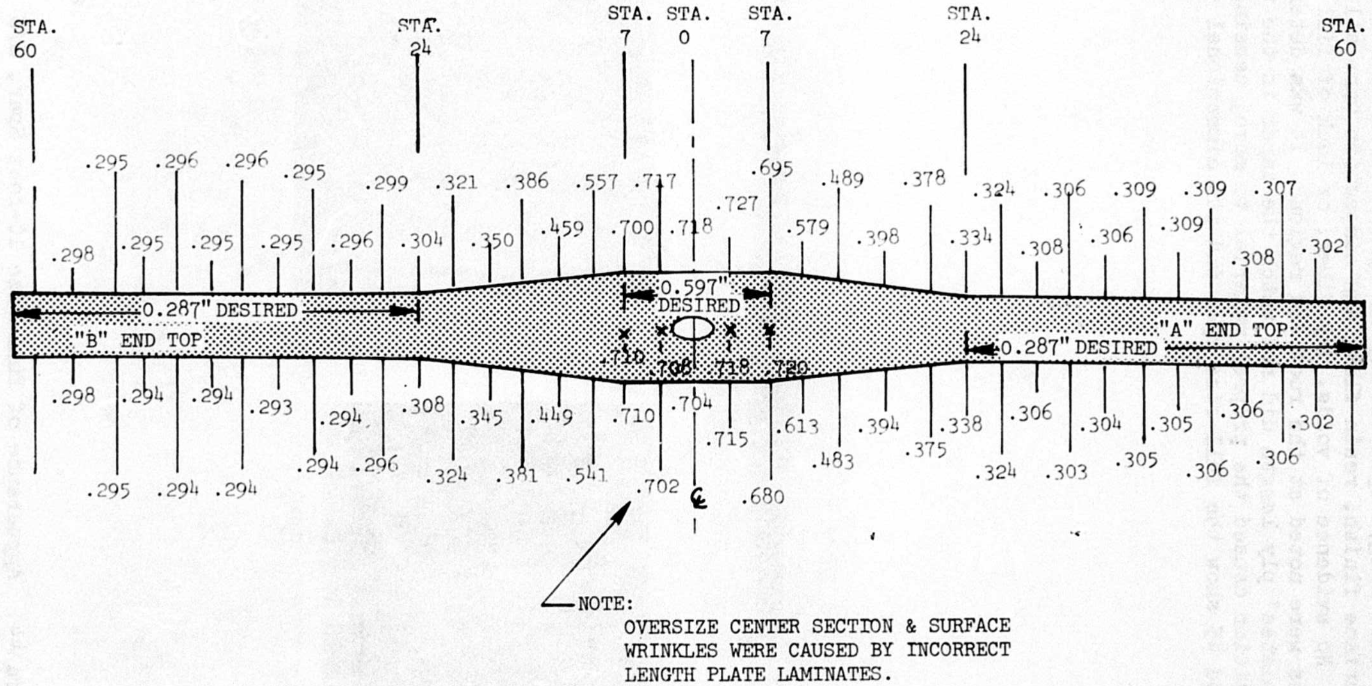


Figure 45. Thickness Variation in 10-foot Spar, S/N 5.

Specimen 6 incorporated prepreg plate plies that were modified to account for the nonlinear spar taper. The full-size spar specimen, 120 inches long, representing the spar from Stations + 60 to - 60, was fabricated without wrinkles and was of excellent visual quality as shown in Figure 46. A nylon peel ply was used when molding this spar. Minor folding of the material caused by movement of the pultrusion during molding and associated with the nylon peel ply resulted in several lengthwise depressions in the constant section of the pultrusion (see Figure 46). The thickness of the constant dimension pultrusion area was within the desired spar thickness but the root end region of the spar was 0.020 to 0.030 inch oversize. Because of the fiberglass buildup area in the spar root end region, the assembly can tolerate up to a 0.050-inch oversize condition. Figure 47 shows the dimensional variation in the spar. Photomicrographs of the pultrusion indicate an absence of voids and dry fibers. Figure 48 depicts typical cross sections at 50 and 250 magnifications. The fiber volume of the spar was measured to be 60 percent. This specimen was selected for use as a full-size root end static specimen.

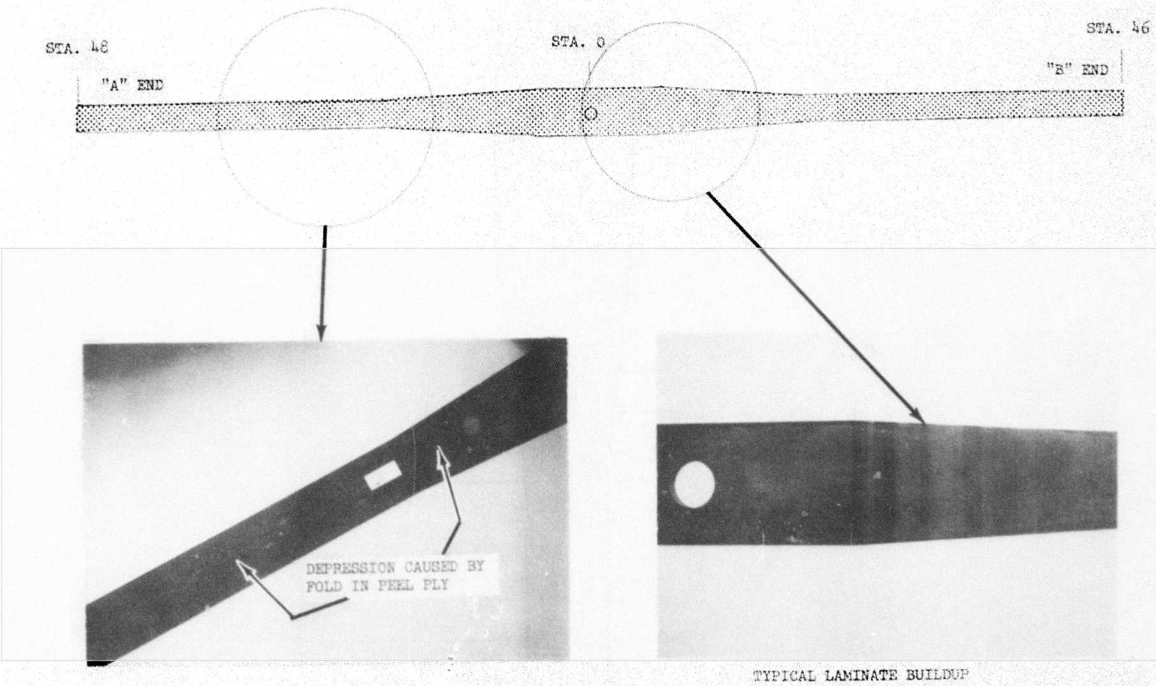


Figure 46. Appearance of Full-Size 10-foot Spar, S/N 6.

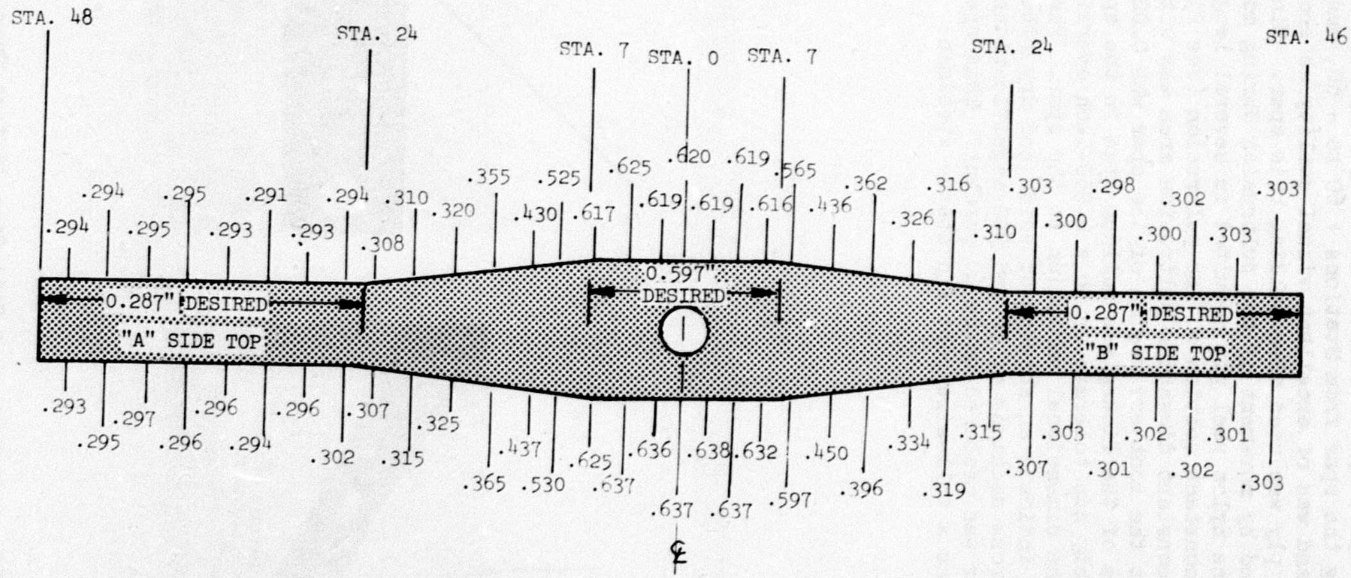


Figure 47. Thickness Variation in 10-foot Spar, S/N 6.

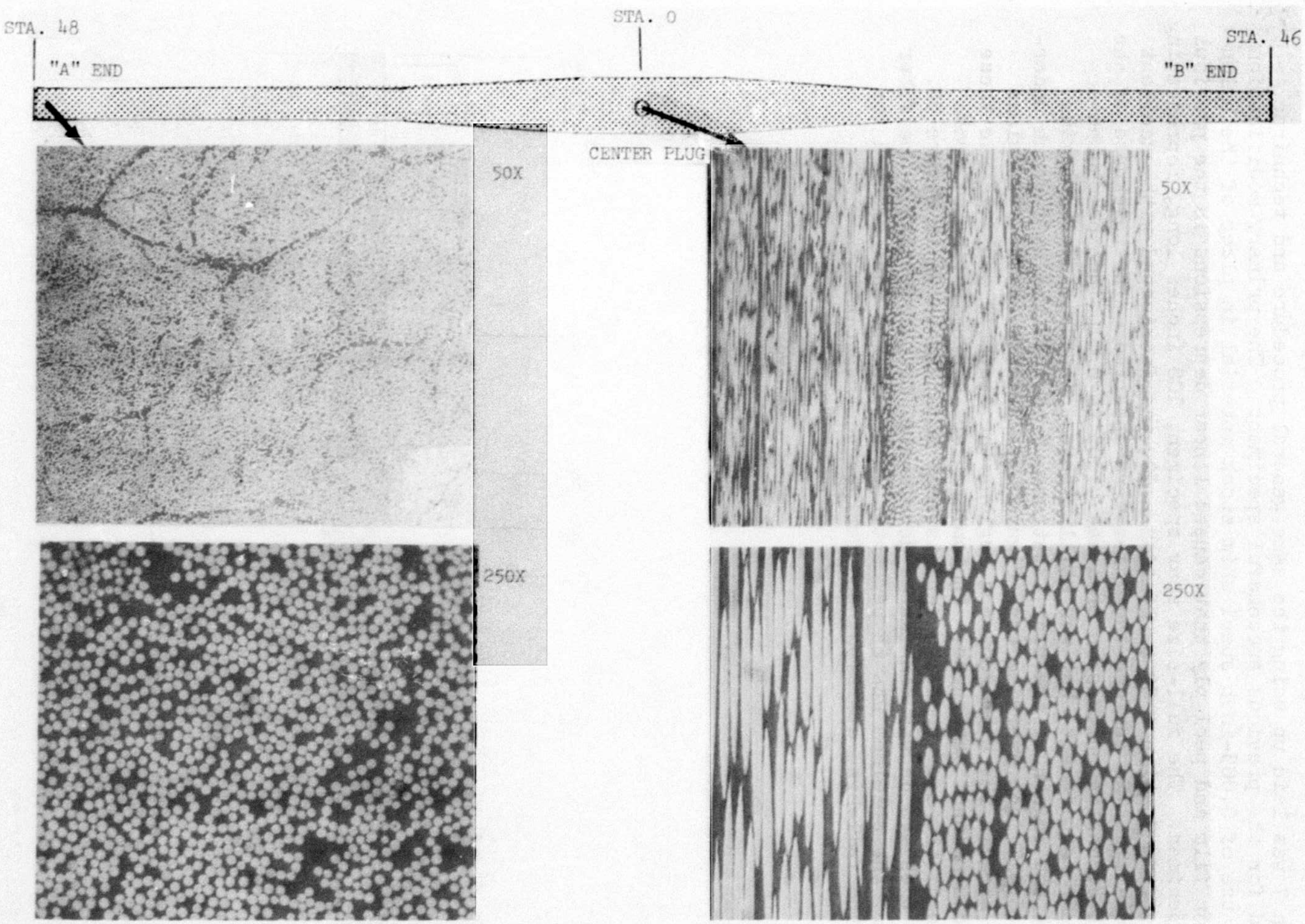


Figure 48. Photomicrographs of Cross Sections of Full-Size Spar, S/N 6.
(Depicting good compaction and absence of voids)

Specimen 7 was laid up using the same general procedure and technique employed for the previous successful specimens. The primary modification was the use of 0.005-inch steel shim stock material in place of the nylon separator film and peel ply that caused linear depressions in the previous S/N 6 specimen. The full-size spar specimen, 100 inches long, representing the spar from Station + 50 to Station - 50, was fabricated with excellent visual quality. No surface anomalies were observed. The thickness of the constant-dimension pultrusion area was 0.005 to 0.010 inch below the desired spar requirement, but was still within acceptable design limits. The root end region of the spar (Station - 7 to + 7) was 0.005 inch undersize to 0.017 inch oversize (see Figure 49). Because of the fiberglass buildup area in the spar root end region, the assembly can tolerate these slight dimensional variances. Photomicrographic examination of cross sections of the spar specimen depicts some voids as shown in Figure 50. None of these voids was considered detrimental to the testing. The fiber volume of the specimen was 65 percent. This specimen was selected for use as the full-size spar root end fatigue test specimen.

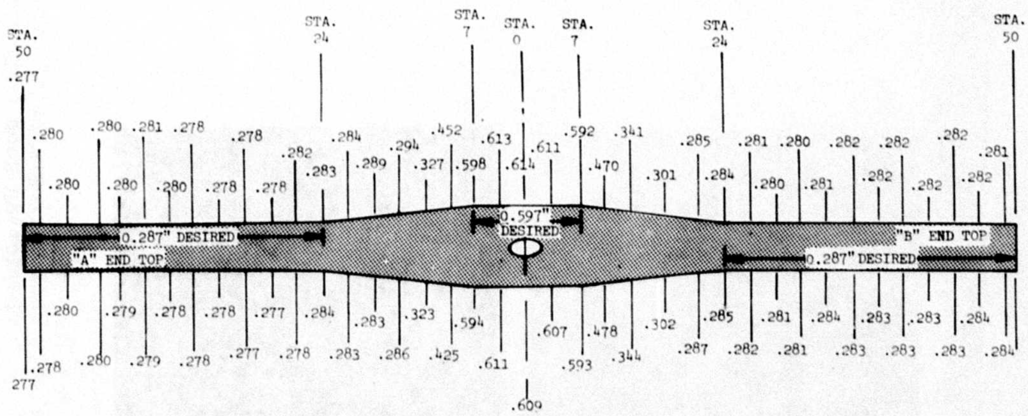


Figure 49. Thickness Variation in 100-inch Spar, S/N 7.

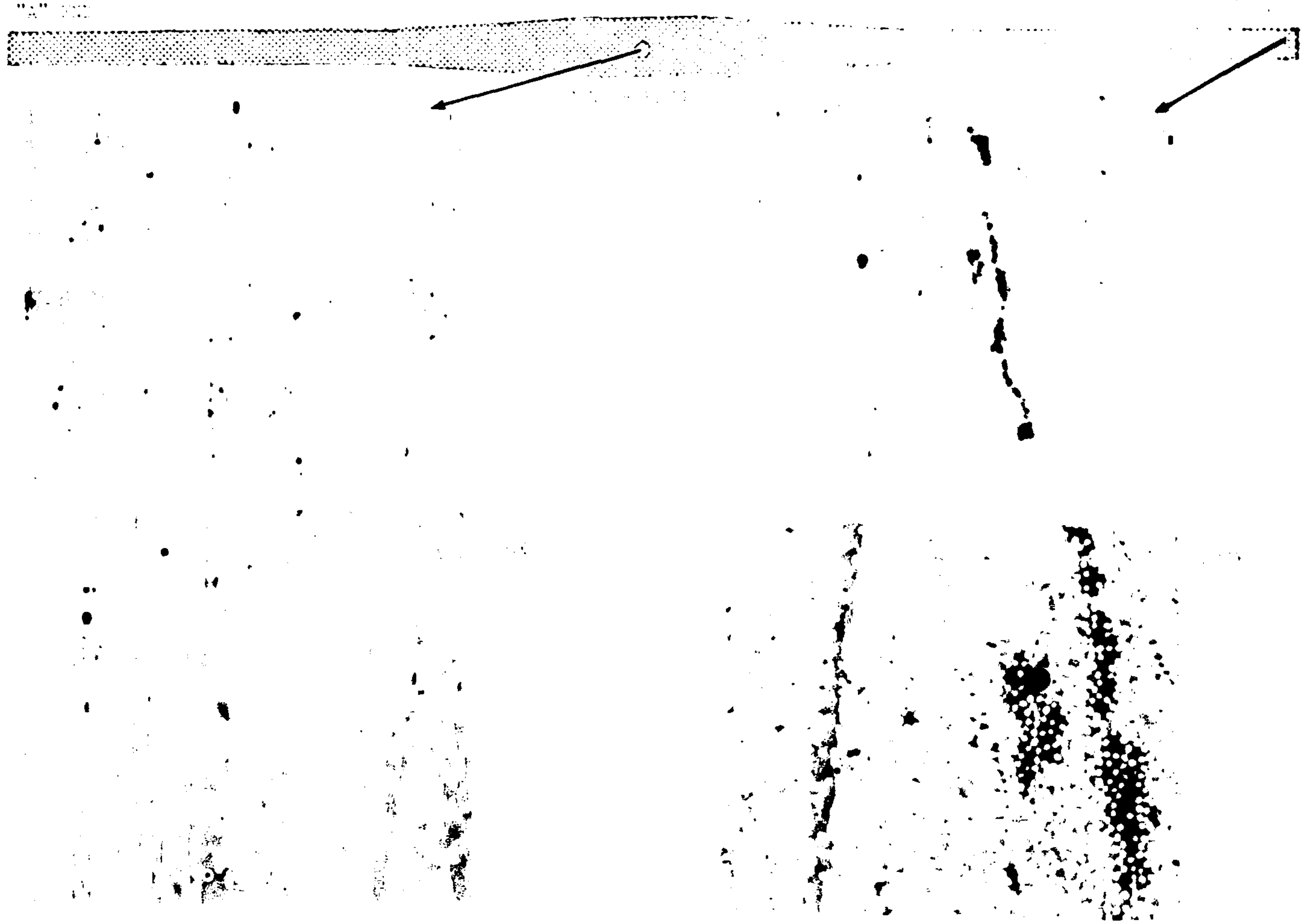


Figure 50. Photomicrographs of Full-Size Spar, S/N 7. (Depicting good compaction and some voids)

A summary of the pultrusion specimen fabrication is provided in Table 11.

Complete assembly drawings including overwraps and the proposed tip weight design were produced as a result of the detailed design. The assembly drawings are provided in Figure 51. An overall view of a typical full-size pultruded tail rotor spar is provided in Figure 52.

Static and Fatigue Root End Test Specimen

Fabrication of full-size static and fatigue specimens was accomplished from sections of the S/N 6 and 7 spars in general accordance with the drawing requirements (Figure 51). After the glass laminate overwrap was applied, the specimens were machined to dimension, including chamfers and radii, and the elliptical hole at the hub region was milled. The buildup of glass plies at the attachment ends was accomplished prior to assembly of the end fittings. An overall view of the static/fatigue specimen with the end fittings installed is provided in Figure 53. Short beam shear tests were performed on material taken from spars S/N 6 and 7. The results show all values exceed specification requirements. The data is provided in Table 12.

Tip Weight Attachment Specimen

Fabrication of the tip weight attachment static test specimen was accomplished from a constant section segment from the "B" end of spar specimen S/N 5 in accordance with the drawing requirements (Figure 51). An overall view of the tip attachment with the end fittings installed is provided in Figure 54. Additional metallurgical examination, volume fraction determination, and short beam shear tests, from Stations 26 and 48 at the "B" end of specimen S/N 5, were performed in order to define more specifically the characteristics of the the tip attachment specimen. All values obtained were comparable to values obtained in the original evaluation of spar S/N 5. Fiber volumes were determined to be approximately 60 percent and short beam shear values were consistently over 14,000 psi. Results are tabulated in Table 13.

TABLE 11. SUMMARY OF PULTRUSION SPECIMEN FABRICATION						
Specimen Serial Number	Specimen Description	Date of Pultrusion	Molding Date At Sikorsky	"B" Staged Pultrusion Comments	Cure Cycle	Comments on Molded Specimens
0	16-inch Constant Thickness	Sept 1976	Oct 1976	No dry ice in package of first two "B" staged spars when received at Sikorsky. Shipment took 4 days. The 2 12-foot pultrusions were advanced beyond use.	325°-350°F @ 100 psi full vacuum. Hold part at temp for two hrs.	Scraped specimen and remaining material due to poor quality of completed specimen.
1,2	30-inch Transition	12 Nov 1976	12 Dec & 15 Dec 1976	Delivery of 2 12-foot lengths by air required 5 days. When received at Sikorsky no dry ice remained in package. The graphite fiber tows were twisted and not uniformly wet with resin.		Lack of resin/fiber wet-out and advancement of the "B" stage resulted in parts containing extensive voids. No compaction, dry fibers, poor surface finish (see Figures 38 and 39).
3	30-inch Transition	5 Jan 1977	10 Jan 1977	113 lb of dry ice in package when received 31 hours after pultruding at GEI. Use of pultrusion production grade fiber, lowered pultrusion rate and increased resin loading eliminated the major fiber twisting & improved the resin/fiber wet-out. Overall quality of both pultrusions was good.	325°-350°F @ 150 psi plus full vacuum. Hold part at temperature for two hrs.	<u>Constant Section Pultrusion (Sta. 24 to 30)</u> Fiber volume 63% (see Figures 40 and 41). Visual quality fair. <u>Tapered Section (Pultrusion/Prepreg, Sta. 24 to 0)</u> Fiber volume 58.4% Undersized fit of prepreg torpedo resulted in a poorly compacted root end which in turn resulted in voids and lack of fill. (See Figures 40 and 41).
4	30-inch Transition		17 Jan 1977			Improved fit of the prepreg torpedo resulted in a completed specimen of excellent quality with no voids in the tapered root end. Fiber volume obtained was 54%. Constant thickness pultrusion contained voids. Pultrusion used was from startup of GEI run and had fibers that were not coated with resin. (See Figures 42 and 43).
5	Full-Size Spar		31 Jan 1977			<u>Constant Section Pultrusion (Sta. 24 to 62)</u> Fiber volume 62%, 0.010 inch over desired thickness, no voids, excellent surface finish. Pultrusions to be used for tip attachment test and rib cover, spar test. (See Figures 44 and 45). <u>Tapered Section (Pultrusion/Prepreg Sta. 0 to 24)</u> Fiber volume 56%, visual quality good, 0.110 inches oversized, wrinkles in root section caused by oversized prepreg ply lengths that did not match the required die taper.
6	Full-Size Spar		21 Feb 1977			S/N 6 prepreg ply length adjustment resulted in a completed spar of excellent visual quality. Spar to be used for full-size static test (see Figures 46 an 47). <u>Constant Section Pultrusion (Sta. 24 to 48)</u> Fiber volume 60% within desired thicknesses, no void excellent surface finish. <u>Tapered Section (Pultrusion/Prepreg Sta. 0 to 24)</u> Fiber volume 55%, visual quality good. 0.050 inch oversize condition.
7	Full-Size Spar	25 April 1977	3 May 1977	152 lb of dry ice in package when received 72 hr after fabrication at GEI. Overall quality of pultrusion was good.		S/N 7 fabricated in accordance with procedure established for S/N 6. S/N 7 exhibited good visual quality. Spar to be used for fatigue test specimen. (See Figures 49 and 50). <u>Constant Section Pultrusion (Sta. 24 to 50)</u> Fiber volume 65% within desired thicknesses, no sig ficant voids, good surface finish. <u>Tapered Section (Pultrusion/Prepreg Sta. 0 to 24)</u> Fiber volume 54%, visual quality good, 0.003-inch undersize to 0.017-inch oversize condition.

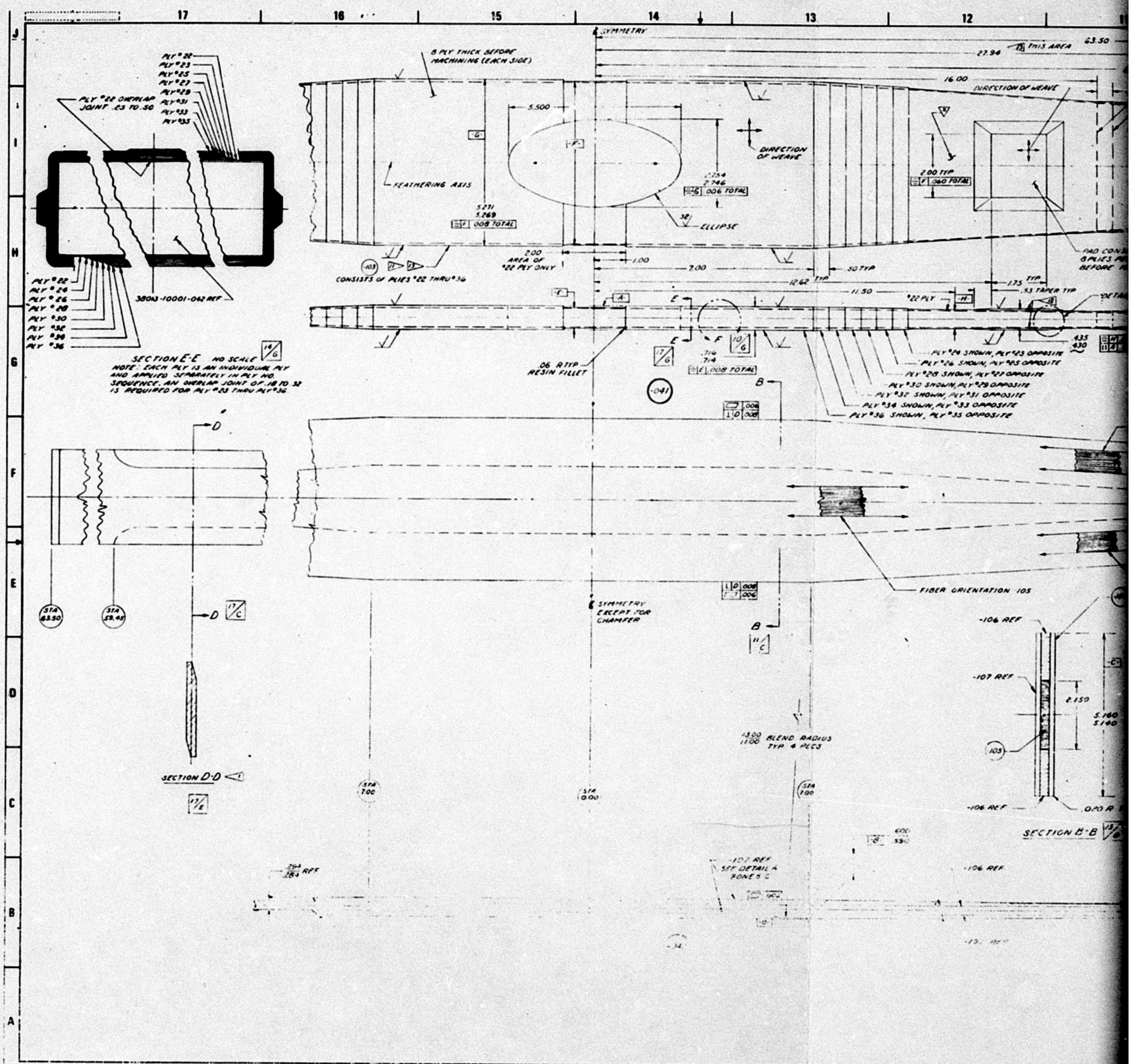


Figure 51. Pultruded Spar Assembly, Tail Rotor Blade.

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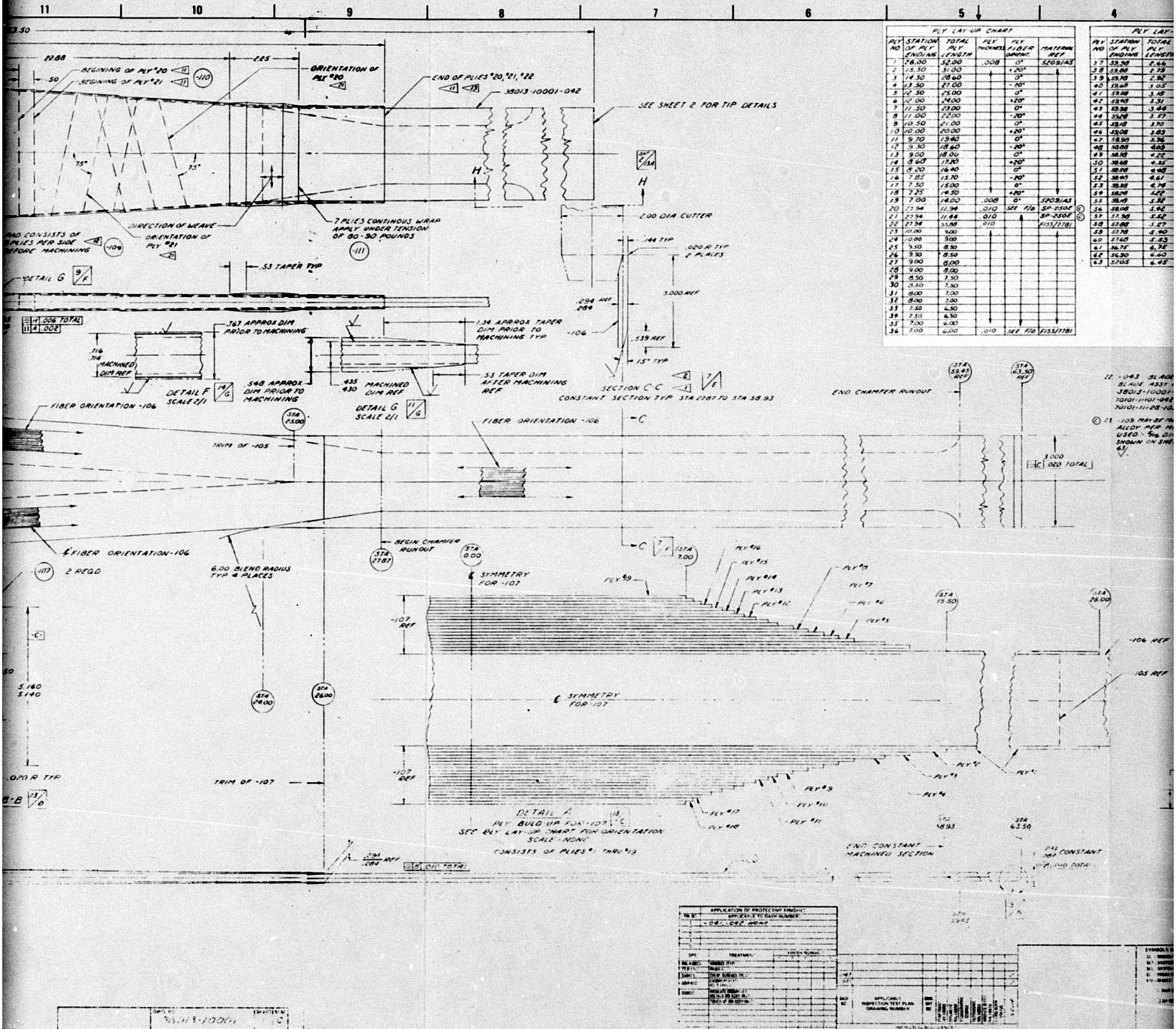
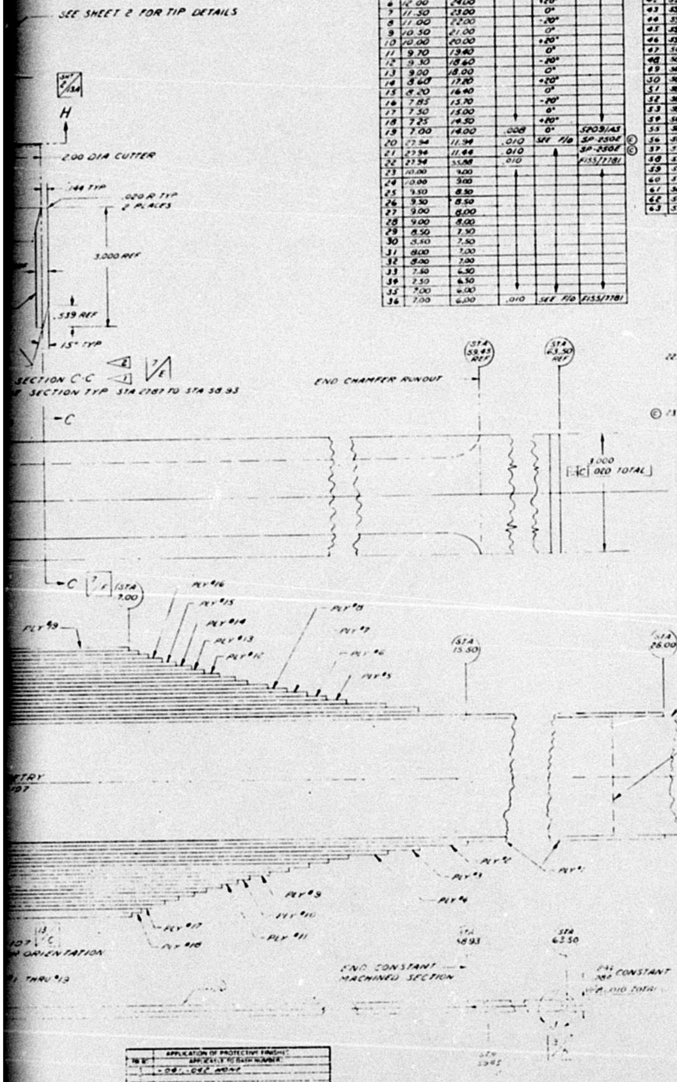
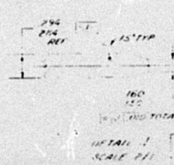


PLY LAY-UP CHART					
PLY NO	STATION OF PLY ENDING	TOTAL PLY LENGTH	PLY THICKNESS	PLY FIBER ORIENT.	MATERIAL REF
1	26.00	52.00	.008	0°	5209/AS
2	15.50	31.00		+20°	
3	14.30	28.60		0°	
4	13.50	27.00		-20°	
5	12.50	25.00		0°	
6	12.00	24.00		+20°	
7	11.50	23.00		0°	
8	11.00	22.00		-20°	
9	10.50	21.00		0°	
10	10.00	20.00		+20°	
11	9.70	19.40		0°	
12	9.30	18.60		-20°	
13	9.00	18.00		0°	
14	8.60	17.20		+20°	
15	8.20	16.40		0°	
16	7.85	15.70		-20°	
17	7.50	15.00		0°	
18	7.25	14.50		+20°	
19	7.00	14.00	.008	0°	5209/AS
20	27.94	11.94	.010	SEE F/0	SP-250E ©
21	27.94	11.44	.010		SP-250E ©
22	27.94	55.88	.010		F155/7781
23	10.00	9.00			
24	10.00	9.00			
25	9.50	8.50			
26	9.50	8.50			
27	9.00	8.00			
28	9.00	8.00			
29	8.50	7.50			
30	8.50	7.50			
31	8.00	7.00			
32	8.00	7.00			
33	7.50	6.50			
34	7.50	6.50			
35	7.00	6.00			
36	7.00	6.00	.010	SEE F/0	F155/7781

PLY LAY-		
PLY NO	STATION OF PLY ENDING	TOTAL PLY LENGTH
37	59.98	2.66
38	59.88	2.79
39	59.78	2.92
40	59.68	3.05
41	59.58	3.18
42	59.45	3.31
43	59.38	3.44
44	59.28	3.57
45	59.18	3.70
46	59.08	3.83
47	58.98	3.96
48	58.88	4.09
49	58.78	4.22
50	58.68	4.35
51	58.58	4.48
52	58.45	4.61
53	58.38	4.74
54	58.28	5.22
55	58.18	5.32
56	58.08	5.42
57	57.98	5.52
58	57.88	5.27
59	57.78	5.40
60	57.65	5.53
61	56.75	6.78
62	56.90	6.60
63	57.05	6.45

REV SYM	RELEASE AUTHORITY	FD ZONE	FIND NO.	DESCRIPTION OF CHANGE
B				NOW SHEET 1 WAS SHEET 2 COMPLETELY REVISED & REDRAWN





PLY LAY-UP CHART

PLY NO	STATION OF PLY ENDING	TOTAL PLY LENGTH	PLY THICKNESS	PLY FIBER ORIENT.	MATERIAL REF
1	26.00	52.00	.008	0°	5209/AS
2	15.50	31.00		+20°	
3	14.30	28.60		0°	
4	13.50	27.00		-20°	
5	12.50	25.00		0°	
6	12.00	24.00		+20°	
7	11.50	23.00		0°	
8	11.00	22.00		-20°	
9	10.50	21.00		0°	
10	10.00	20.00		+20°	
11	9.70	19.40		0°	
12	9.30	18.60		-20°	
13	9.00	18.00		0°	
14	8.60	17.20		+20°	
15	8.20	16.40		0°	
16	7.85	15.70		-20°	
17	7.50	15.00		0°	
18	7.25	14.50		+20°	
19	7.00	14.00	.008	0°	5209/AS
20	27.94	11.94	.010	SEE F/O	SP-250E (C)
21	27.94	11.44	.010		SP-250E (C)
22	27.94	55.88	.010		F155/7781
23	10.00	9.00			
24	10.00	9.00			
25	9.50	8.50			
26	9.50	8.50			
27	9.00	8.00			
28	9.00	8.00			
29	8.50	7.50			
30	8.50	7.50			
31	8.00	7.00			
32	8.00	7.00			
33	7.50	6.50			
34	7.50	6.50			
35	7.00	6.00			
36	7.00	6.00	.010	SEE F/O	F155/7781

PLY LAY-UP CHART

PLY NO	STATION OF PLY ENDING	TOTAL PLY LENGTH	PLY THICKNESS	PLY FIBER ORIENT	MATERIAL REF
37	59.98	2.66	.008	-45°	5209/AS
38	59.88	2.79		0°	
39	59.78	2.92		+45°	
40	59.68	3.05		0°	
41	59.58	3.18		-45°	
42	59.48	3.31		0°	
43	59.38	3.44		+45°	
44	59.28	3.57		0°	
45	59.18	3.70		-45°	
46	59.08	3.83		0°	
47	58.98	3.96		+45°	
48	58.88	4.09		0°	
49	58.78	4.22		-45°	
50	58.68	4.35		0°	
51	58.58	4.48		+45°	
52	58.45	4.61		0°	
53	58.38	4.74		-45°	
54	58.28	5.22		0°	
55	58.18	5.32		+45°	
56	58.08	5.42		0°	
57	57.98	5.62		-45°	
58	57.88	5.87		0°	
59	57.78	5.90		+45°	
60	57.65	5.53		0°	
61	56.75	6.75		0°	
62	56.90	6.60		-45°	
63	57.05	6.45	.008	+45°	5209/AS

NOTES CONT'D

22. -043 BLADE ASSY SAME AS 70101-11100-045 BLADE ASSY EXCEPT ADD 1 REQUIRED OF 38013-10001-041 SPAR ASSY, OMIT 1 REQUIRED 70101-11101-042, OMIT 2 REQUIRED OF 70101-11128-106, 70101-11128-103 COUNTERWEIGHTS.

(C) 23. -109 MAY BE MADE FROM TYPE 3, COMP A, 6AL-4V TITANIUM ALLOY PER MIL-T-9047 BAR STOCK. STOCK SIZE TO BE USED - 9/16 DIA OR LARGER. THREAD CALLOUT ON -109 AS SHOWN ON SHEET 2 TYP BOTH ENDS. SURFACE ON [R] (HA) 63√.

NOTES

1. SECTION D-D IS OPPOSITE SECTION C-C.
2. CHAMFERS TO BE MACHINED AFTER MOULDING TO 63√ FINISH.
3. BOND AT THESE SURFACES WITH ONE THICKNESS OF SS8612 002 ADHESIVE.
4. 70101-11102-041-T60 LAY UP TEMPLATE SHALL BE USED TO DEFINE SHAPE OF -105 CENTER PLUG. -105 TO CONSIST OF 37 PLIES (.008 THICKNESS PER PLY).
5. BREAK ALL SHARP CORNERS .005-.015 RADIUS ON ALL COMPOSITE MATERIAL UNLESS OTHERWISE NOTED.
6. -106 PULTRUSION SHALL BE PROCESSED BY GOLDWORTHY ENG INC IN ACCORDANCE WITH SES 701174.
7. FABRICATE IN ACCORDANCE WITH SS9583, CLASS "S".
8.
9. SURFACES MARKED √ TO HAVE 125√ EXCEPT AS NOTED. SS5100 SHALL APPLY FOR HOLES UNLESS OTHERWISE INDICATED. AREAS OF TRANSITION SHALL CONFORM TO THAT SPECIFIED FOR THE ROUGHEST ADJACENT FINISHED AREA UNLESS OTHERWISE INDICATED.
10. PLY BUILD-UP FOR -102 SEE CHART SHEET 1, ZONE 4,5 J FOR PLY ORIENTATION ANGLE, THICKNESS AND SIZES. PLIES #61, #62, #63 TO BE BONDED AFTER MACHINING OF -041 TIP ENDS. SEE SECTION L-L, M-M, N-N, R-R.
11. -103 (PLIES #22 THRU #36) NOT TO BE BONDED UNTIL -110 WRAP (PLIES #20, #21) ARE APPLIED. SEE SHEET 1, ZONE 15,16 H.
12. -104 PAD TO BE CO-CURED TO ONE PLY GLASS WRAP AT TIME OF -103 CENTER WRAP CURE.
13. BOND -103, -110 WITH M1113 ADHESIVE PER SES 701174 TO STA 27.94 INCLUSIVE. (ADHESIVE TO BE BETWEEN SPAR AND FIRST LAYER OF PREIMPREGNATED FIBERGLASS.)
14. AFTER MACHINING -101, SHOT PEEN ALL OVER EXCEPT HOLES WITH S 70 STEEL SHOT TO .005-.009 N INTENSITY PER SS8746. DIMENSIONS SHOWN ARE AFTER SHOT PEENING.
15. HAND FIT -101 TO -042 SO AS TO COMPRESS GRAPHITE AS NUTS ARE TORQUED. BOND -101 TO -042 IN ACCORD WITH SES-701174.
16. -103 CONSISTS OF ONE REQD OF PLY #22 AND 2 REQD OF PLIES #23 THRU #36.
17. BOND BUSHINGS WITH EA9309.2 ADHESIVE PER SES-701174.
18.
19. USE AN316-4 (2 PER STUD) DURING BALANCING ONLY.
20. HOLD SCREW BY SCREW DRIVER SLOT WHILE APPLYING TORQUE.
21. PLY #20, #21 (-110), DUE TO SPAR TAPER GAPS ACCEPTABLE BETWEEN EDGES OF WRAPS. CONTINUOUS WRAP FOR EACH PLY. APPLY UNDER TENSION OF 10-30 POUNDS.

REFER TO SHEET 2 FOR PARTS LIST & BILL OF MATERIAL

APPLICATION OF PROTECTIVE FINISHES

-041, -042 NONE

SIKORSKY AIRCRAFT
STRATFORD CONNECTICUT 06602

ORIGINALLY PREPARED UNDER CONTRACT NUMBER DAAJ02-78-C-0301

PULTRUDED SPAR ASSY — TAIL ROTOR BLADE

J 78286 38013-10001

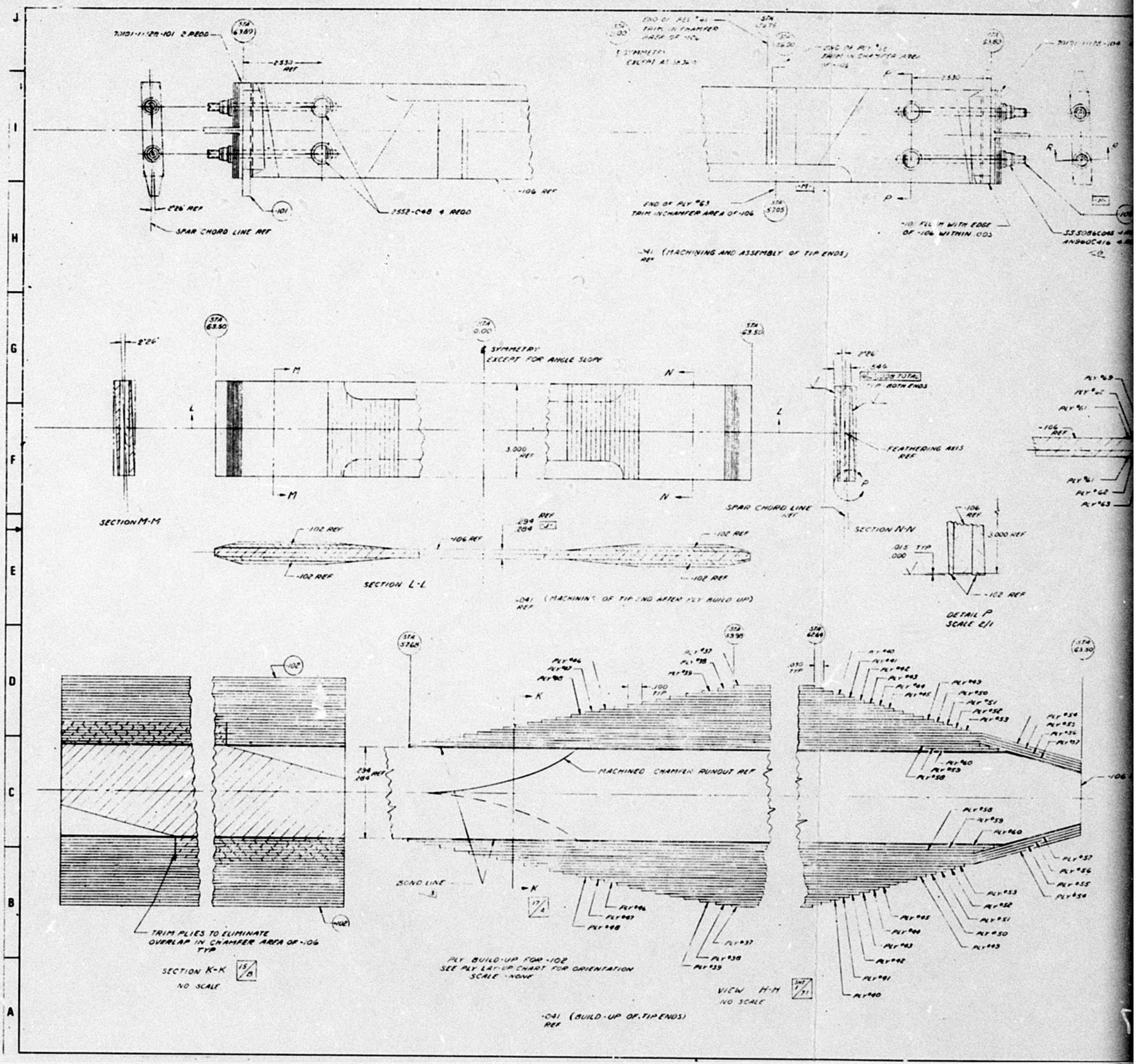


Figure 51. (Continued)

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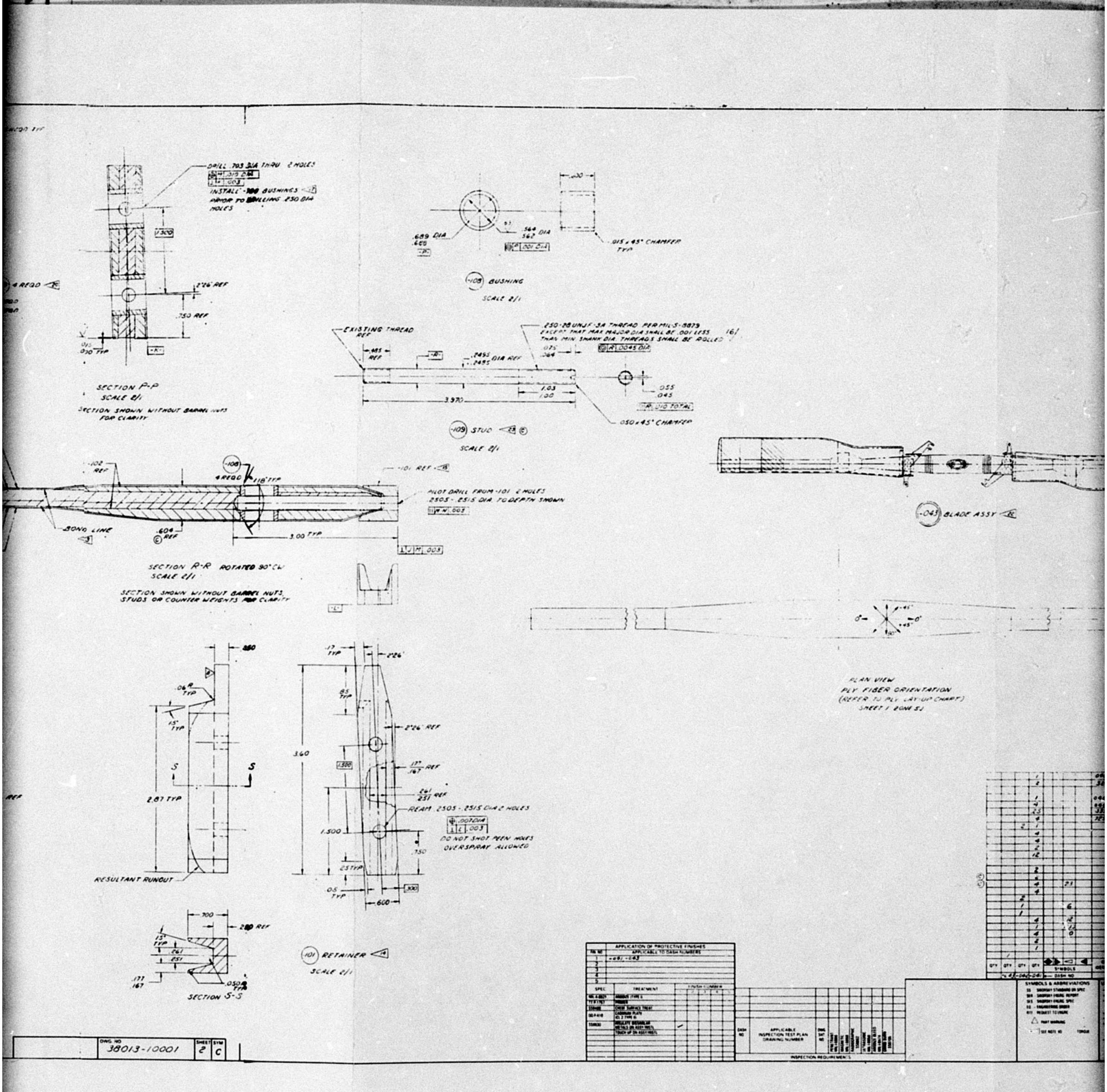

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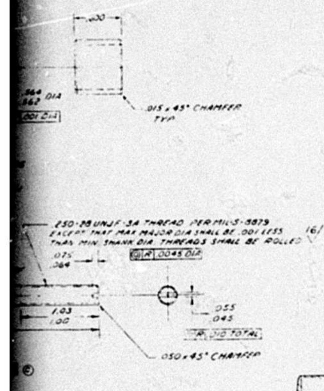
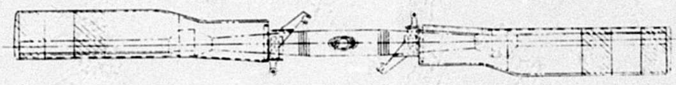


2 HOLES
DEPTH SHOWN



-043 BLADE ASSY

SEE SHEET 1 FOR NOTES

PLAN VIEW
PLY FIBER ORIENTATION
(REFER TO PLY LAY-UP CHART)
SHEET 1 ZONE 5J

HOLES

HOLES
SHOWN

REV SYM	RELEASE AUTHORITY	P.O. ZONE	FIND NO.	DESCRIPTION OF CHANGE
N				NEW SHEET 2 WAS SHEET 1 COMPLETELY REVISED & REDRAWN
	ENG	2L		INCORP E.O. 43878 IN P/L: NEW - 38013-10001-110 3-PLY; WAS - 38013-10001-110 1-PLY; SECTION P-P ADDED -109 (REF)
		7C 3C		INCORP E.O. 48454 ADDED 43; IN P/L ADDED .03 IN NOTES COLUMN

QTY	QTY	QTY	QTY	SYMBOLS	CODE IDENT NO	PART NUMBER	NOMENCLATURE	SPECIFICATION	STOCK SIZE	MATERIAL OR NOTE	UNIT WT	ZONE
			1		04963	EC3917	PRIMER		AR			
			2		32617	MILTEX 3161	PEEL PLY		SQ FT			
						38013-10001-043	BLADE ASSY					
			1		04662	M6726	PRIMER		AR			
			4		04662	M1113 (.06 WT)	ADHESIVE		SQ FT			
			25		33564	EA9309.2	ADHESIVE		SQ FT			
			4		72962	2552-048	NUT, BARREL					
	2		1			M-1113 (.03 WT)	ADHESIVE		SQ FT			
			4			AN960C416	WASHER					
			4			SS5066C04S	NUT					
			2			38013-10001-111	WRAP-EXTERNAL	SS9578-003				
			12			70101-11128-104	COUNTER WEIGHT					
			2			70101-11128-101	COUNTERWEIGHT					
			4			38013-10001-110	WRAP-INTERNAL	SP-250E	1.0 WIDE	PLIES 20 THRU 21		
			4	21		-109	STUD			MIF NAS 1271-58		
			4			-108	BUSHING	MIL-T-9047		TYPE 3 COMPA GAL-4V Ti ALY		
		2				-107	CENTER BUILD-UP	5209/AS		PLIES 1 THRU 19		
		1		6		-106	PULTRUSION					
		1				-105	CENTER PLUG	5209/AS				
			4	12		-104	PAD	F155/7781				
			1	11/12		-103	CENTER WRAP	F155/7781		PLIES 22 THRU 36		
			4	10		-102	TIP PLY BUILD UP	5203/AS		PLIES 37 THRU 63		
			2			-101	RETAINER	MIL-T-9047		TYPE 3 COMPA GAL-4V Ti ALY		
			1			-042	SPAR, ASSY OF					
	1					38013-10001-041	SPAR ASSY					
-043	-042	-041		DASH NO								

LIST OF MATERIAL AND PARTS LIST

FIN NO	APPLICATION OF PROTECTIVE FINISHES APPLICABLE TO DASH NUMBERS
1	-041, -043
2	
3	
4	
5	

SPEC	TREATMENT	FINISH NUMBER 1	2	3	4	5
MIL-A-8625	ANODIZE (TYPE I)					
TT-P-1757	PRIMER					
SS8480	CHEM. SURFACE TREAT					
QQ-P-416	CADMIUM PLATE (CL 2 TYPE II)					
SS8630	INSULATE DISSIMILAR METALS (IN ASSY INST.)	✓				
	TOUCH UP (IN ASSY INST.)					

DASH NO	APPLICABLE INSPECTION TEST PLAN DRAWING NUMBER	DWG SHT NO	PENETRANT	MAGNETIC	RADIOGRAPHIC	ULTRASONIC	HARDNESS	CONDUCTIVITY

INSPECTION REQUIREMENTS

SYMBOLS & ABBREVIATIONS
SS SIKORSKY STANDARD OR SPEC
SER SIKORSKY ENGRG REPORT
SES SIKORSKY ENGRG SPEC
EO ENGINEERING ORDER
RTE REQUEST TO ENGRG
PART MARKING
SEE NOTE NO. TORQUE

UNLESS OTHERWISE SPECIFIED

DRAWN BY | PERRIT
DESIGNER
DESIGN SUPV
DESIGN CHKR
RECORD CHKR
STRUCT ANAL
STRUCT SUPV
MATERIAL
FINISH
MASS PROP
SYS ENGR

ORIGINALLY PREPARED UNDER CONTRACT NUMBER DAAJ02-76C-0001
RELEASE AUTHORITY
TASK MANAGER DATE
RELEASE GROUP DATE
GOVERNMENT DATE

SIKORSKY AIRCRAFT
STRATFORD CONNECTICUT 06602

DRAWING TITLE
PULTRUDED SPAR ASSY — TAIL ROTOR BLADE

SIZE	FSCM NO	DRAWING NUMBER
J	78286	38013-10001

SCALE NONE | SHEET 2 OF

DWG NO 38013-10001

Figure 52. Full-Size Pultruded Tail Rotor Spar.

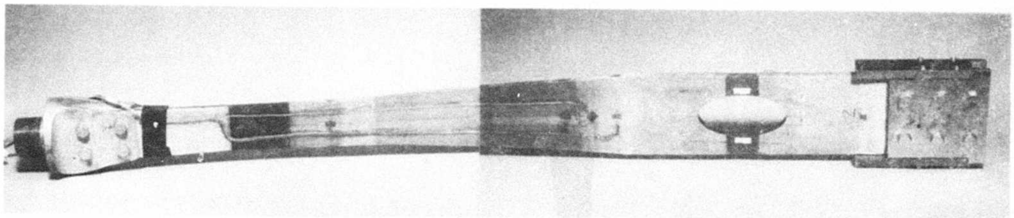


Figure 53. Static/Fatigue Specimen With End Fittings Installed.

TABLE 12. SUMMARY OF SHORT BEAM SHEAR TEST OF MATERIAL FROM SPARS S/N 6 AND 7

Spar S/N	Specimen	Shear Strength (psi)
6-"B" End	1	13,349
	2	13,805
	3	15,479
	4	14,119
	AVG	14,188
7-"A" End	1	11,000
	2	11,600
	3	11,679
	4	10,638
	AVG	11,245
7-"B" End	1	12,761
	2	14,718
	3	14,238
	4	13,798
	AVG	13,877
7-Center Plug	1	14,142
	2	14,382
	3	14,053
	4	15,023
	AVG	14,400
Requirement		11,000

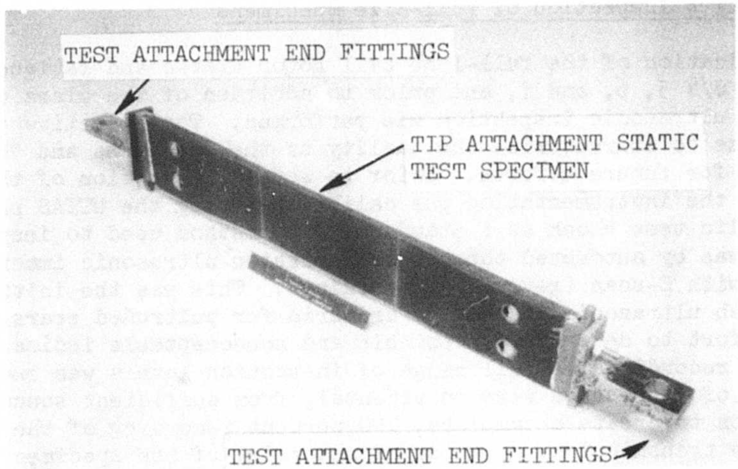


Figure 54. Tip Attachment Specimen With Test Attachment End Fittings Installed.

TABLE 13. SUMMARY OF SHORT BEAM SHEAR TEST OF MATERIAL FROM SPAR SPECIMEN S/N 5

Spar	Specimen	Short Beam Shear Strength (psi)
Station 24 "B" End	1	15,050
	2	14,380
	3	16,420
	AVG	15,280
Station 49 "B" End	1	14,610
	2	15,590
	3	16,100
	AVG	15,430
Requirement		11,000

Nondestructive Inspection of Full-Size Specimens

After fabrication of the full-size tail rotor static and fatigue spar specimens, S/N 5, 6, and 7, and prior to addition of the glass doublers and wraps, ultrasonic inspection was performed. The objective of the inspection was to characterize the quality of the specimens and to establish a baseline for future efforts. Prior to actual inspection of the test specimens, the instrumentation was calibrated using the UTTAS production clear acrylic test block as a standard. The method used to inspect the specimens was by automated through-transmission ultrasonic immersion technique with C-scan (x-y plot) recordings. This was the initial effort to establish ultrasonic inspection criteria for pultruded spars. As part of this effort to determine acceptable and nonacceptable indications on the C-scan recordings, a full range of inspection levels was employed. The levels of inspection were incremental, from sufficient sound energy transmission to create a complete, 100 percent recording of the specimen to no sound transmission, creating no recording of the specimen. The actual levels of inspection were from 2 dB to 56 dB, generally in 4 dB increments, with approximately 14 different C-scan recordings. Interpretation of the recordings at the time of inspection could not be accomplished due to the lack of or limited experience with pultruded spars. Interpretation of the recordings was deferred until static and fatigue testing had been accomplished. Upon completion of the static and fatigue testing, the separated specimens were compared to the C-scan recordings in an effort to determine if the test failure location manifested any indication on the C-scan recordings and at what inspection level the indications were manifested. The comparison would ascertain if the test failure could have been predicted. Discussion of the C-scan recordings and their interpretation are provided in the section on Static Root End Test and Evaluation.

PHASE IV - FULL-SCALE STATIC AND FATIGUE SPECIMEN TESTING AND EVALUATION

This phase of the program entailed actual static and fatigue testing of pultruded component hardware specimens to failure, and evaluation of the test data. The original contract was directed at the YUH-60A, UTTAS (prototype UH-60A, BLACK HAWK) tail rotor design and used that prototype design as a baseline for comparison of structural test results. In general, the subject program was successful technically. However, as a result of increased design load requirements obtained during actual flight evaluation of the YUH-60A, UTTAS (prototype UH-60A, BLACK HAWK) aircraft, modification to the production BLACK HAWK tail rotor design occurred and subsequently impacted the subject program. The primary modification to the production BLACK HAWK tail rotor spar was the redesign of the torque rib/spar joint, which was directly reflected in the pultrusion design. This change in design of the production spar resulted in a more complicated pultruded spar design that required a redirection of the program in order to maintain direct applicability to the production tail rotor design. Static and fatigue testing of the pultruded spar root end demonstrated that the pultruded root end design met the original design load requirements of the UTTAS spar, but was unacceptable with respect to meeting the increased production design fatigue requirements. Design modifications to the pultruded root end were identified and resulted in a proposed new pultruded root end design that was capable of meeting the new higher design load requirements. The proposed redesigned pultruded spar root end is discussed in this section and further detailed in Phase V.

Test Support Equipment

Design of the test support equipment necessary to accomplish static testing of the tip attachment specimen, and static and fatigue testing of the root end spar test specimens was accomplished. Drawings of the equipment are provided in Figures 55, 56, 57, and 58.

Tip Attachment Static Test and Evaluation

Analytical analysis of the tip weight area indicated that the 38013-10001-109 studs were the most critical components. In order to verify the adequacy of the -109 stud, a risk reduction test was conducted. The risk reduction effort for the tip weight consisted of an axial tensile test with an arrangement that simulates the design concept utilizing the 2552-048 barrel nut at one end and the SS5086C04S nut at the other end. As expected, the -109 stud failed in the threads and the load required to rupture the stud was 1.5 times the minimum load required, as calculated.

Static testing of the tip attachment specimen was accomplished in axial tension loading at room temperature. Failure of the specimen occurred after 9,250 pounds axial load was attained. This value is well above the design load of 8,150 pounds. Failure of the tip attachment specimen occurred through the threaded area of one of the -109 studs, as shown in Figures 59 and 60. During testing, one of the T-fittings that attach the specimen to the testing machine was observed to have bent as shown in

Figure 60. Bending of the T-fitting also introduced bending as well as axial loads on the studs and directly influenced failure of the studs. A stronger attachment fitting was fabricated and the tip attachment specimen was retested. Only the end of the specimen, which previously did not fail, was retested. The end that originally failed was secured in the test facility by wedge-type grips. A value of 11,600 pounds axial load was attained before failure of the tip attachment specimen occurred. This value is well above the tensile allowable of 8,150 pounds and the previous value of 9,250 pounds for the other end of the test specimen. Failure of the tip attachment specimen retest occurred by stripping the threads of one of the SS5086C04S nuts. This failure mode differs from the original failure mode through the threaded area of one of the -109 studs. Figure 61 shows the tip attachment static setup at the retest end before testing, while Figures 62 and 63 depict the tip attachment specimen after testing.

The value of 11,600 pounds axial load attained from the testing of the pultruded design tip attachment assembly is 185 percent above the design ultimate load requirement of 6,240 pounds.

Static Root End Test and Evaluation

Static Root End Testing. The static test of the root end was conducted on spar specimen S/N 6 as part of the program to verify the structural adequacy of the pultruded tail rotor spar. Actual testing was conducted in the 40,000-pound blade test facility. The spar was instrumented with flatwise and edgewise strain gauge pairs, and torque bridge strain gauges. The strain gauges were calibrated by the incremental application of known moments. Testing was performed initially in accordance with an approved test plan. However, following nonfracture of the specimen at the initial test conditions, the test conditions were modified and several other more severe conditions were imposed that subsequently induced fracture.

The spar specimen was installed in the test facility at a specified angle in order that the edgewise and flatwise bending moments could be applied by a single hydraulic cylinder with the proper edgewise-to-flatwise ratio. The bending loading hydraulic cylinder was located at the pinned attachment at the outboard end of the spar specimen. A twist was applied to the specimen to obtain the desired torque. The twist was obtained by means of a torsional loading hydraulic cylinder located at the root end of the specimen. The centrifugal load was applied by means of Bellville springs and calibrated loading straps. Figure 64 depicts the test setup prior to the application of edgewise and flatwise moments. Edgewise and flatwise moments were then applied to the specimen by means of the bending loading hydraulic cylinder. At this time, the spar met the original design loads, Condition 1 in Table 14.

The bending moments were then increased incrementally by means of the bending loading cylinder. At the same time, because of the deflection involved and the fixed position of the torsion cylinder and Bellville springs, torsional and centrifugal loading were forced to increase. Loads were increased until the maximum stroke of the bending loading hydraulic

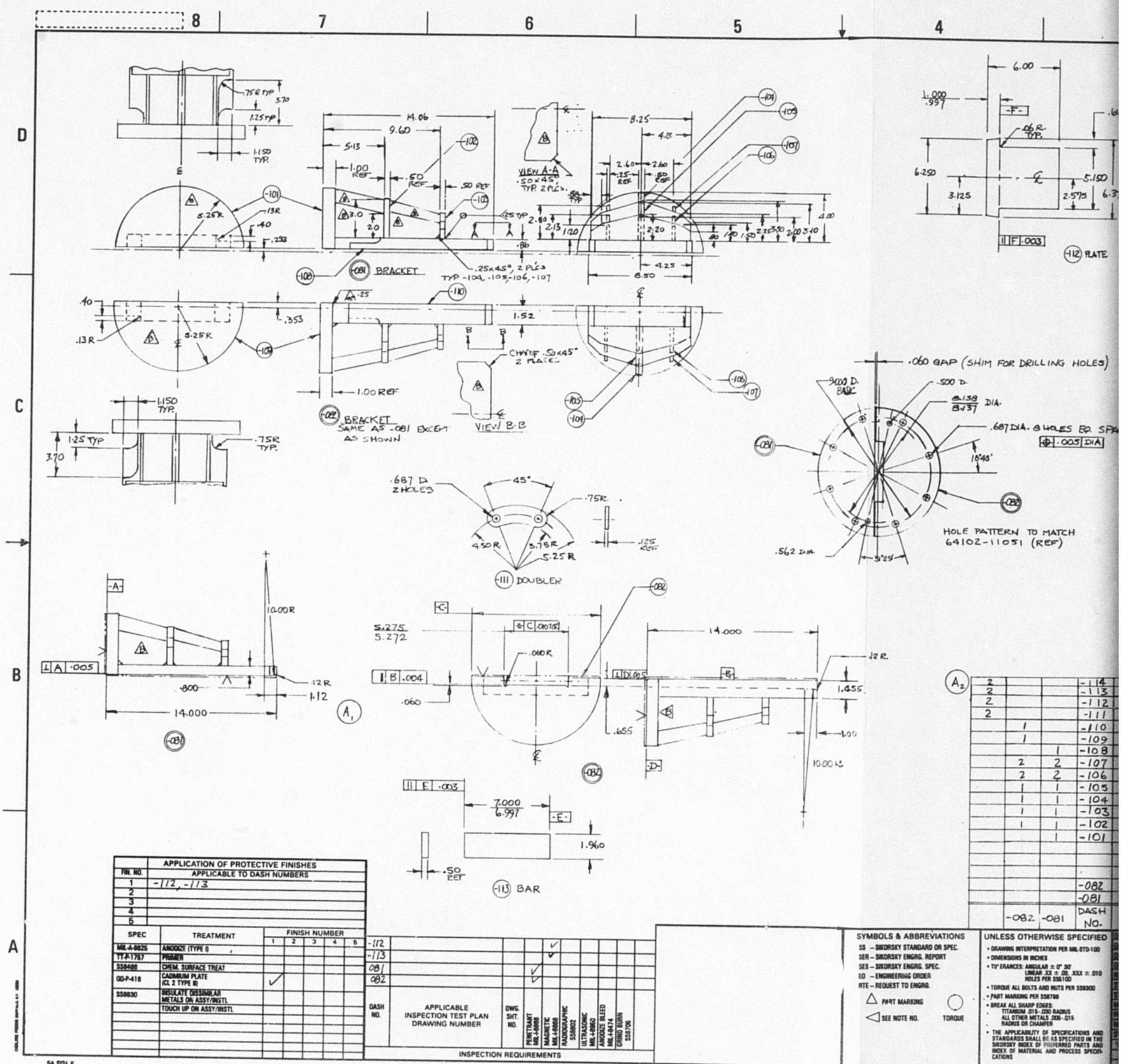


Figure 55. Pultruded Tail Rotor Spar Test Mounting Fixture.

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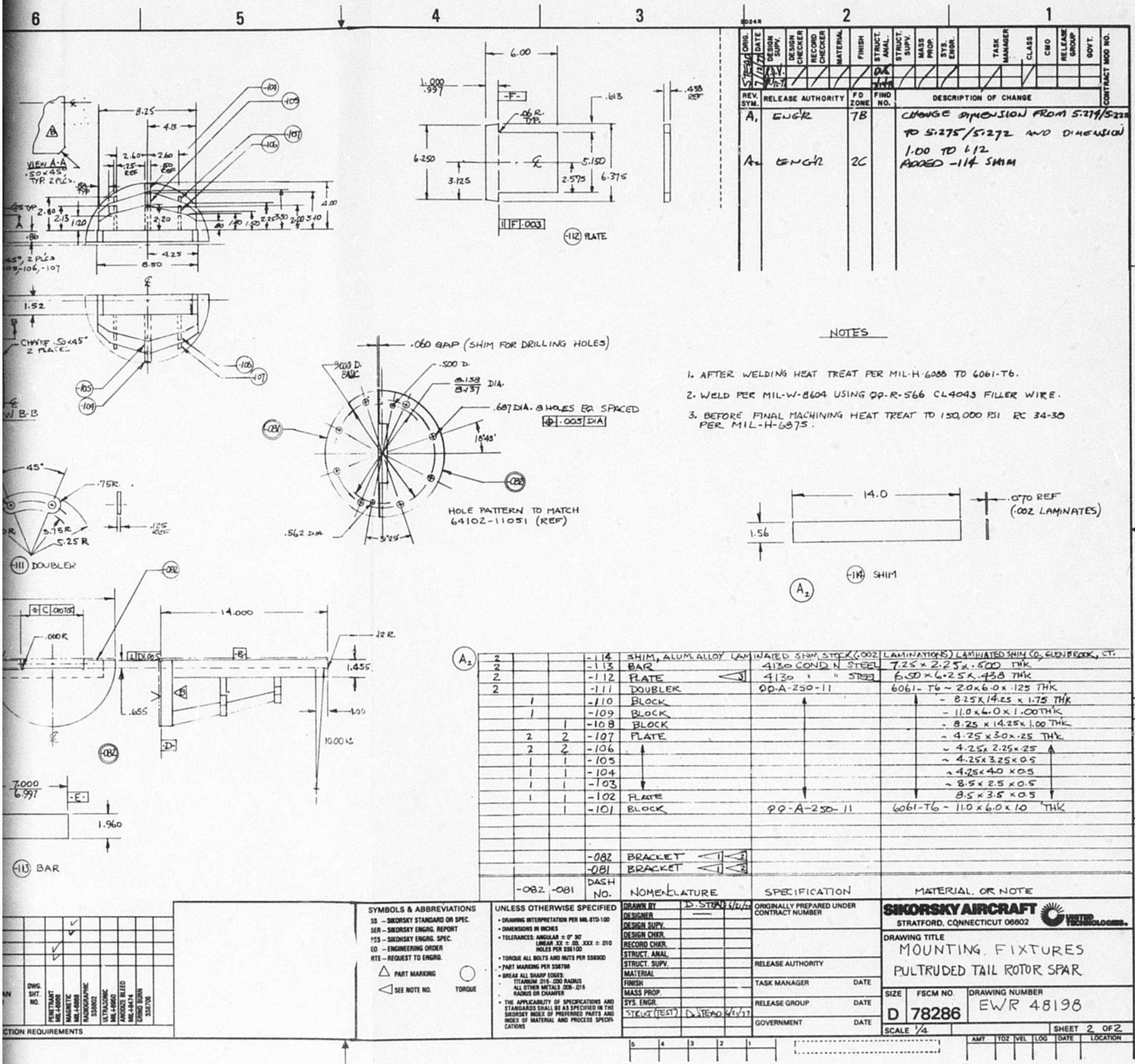

Test Mounting Fixture.

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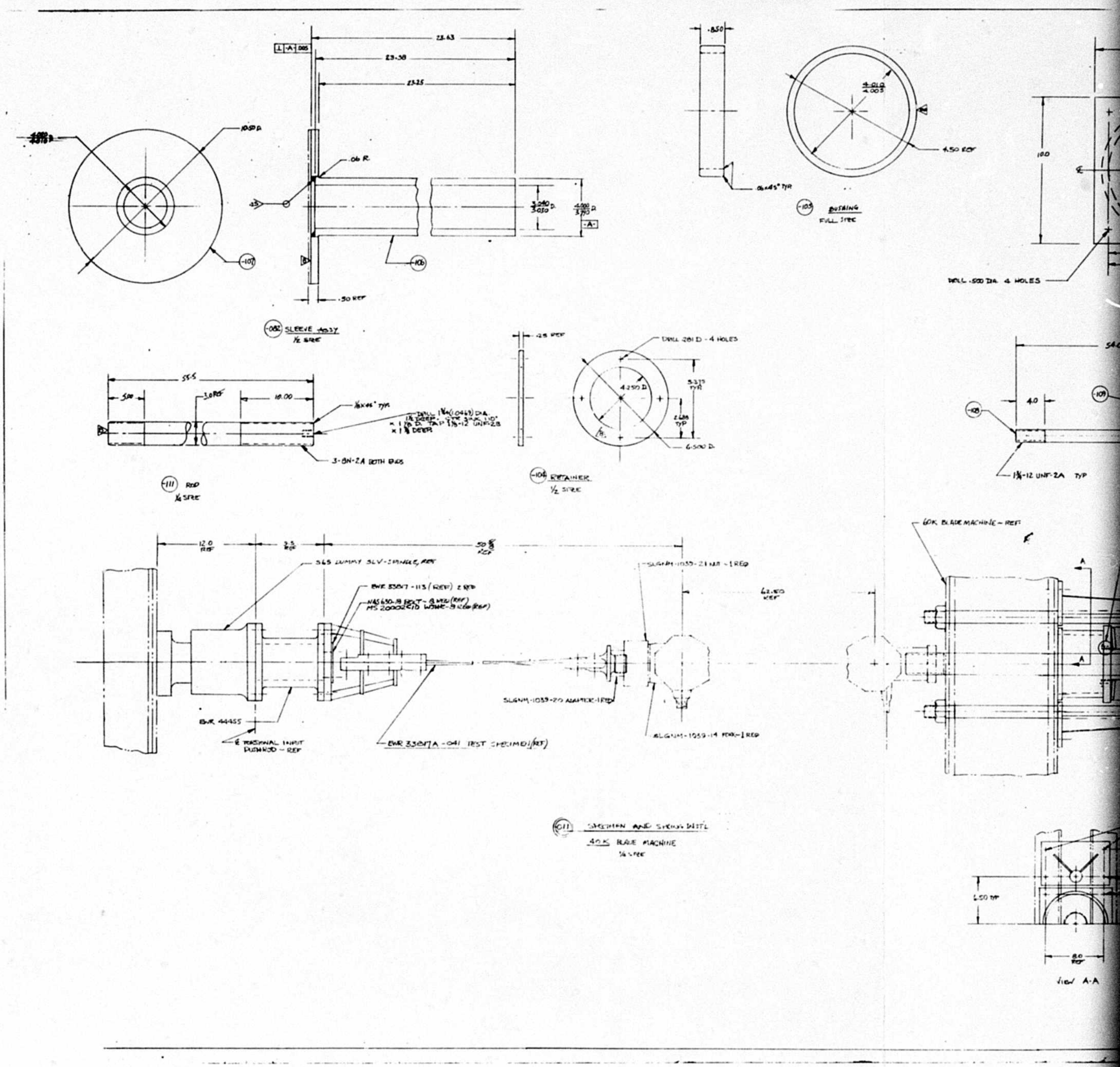

Figure 56. Pultruded Tail Rotor Spar Fatigue Test Installation.

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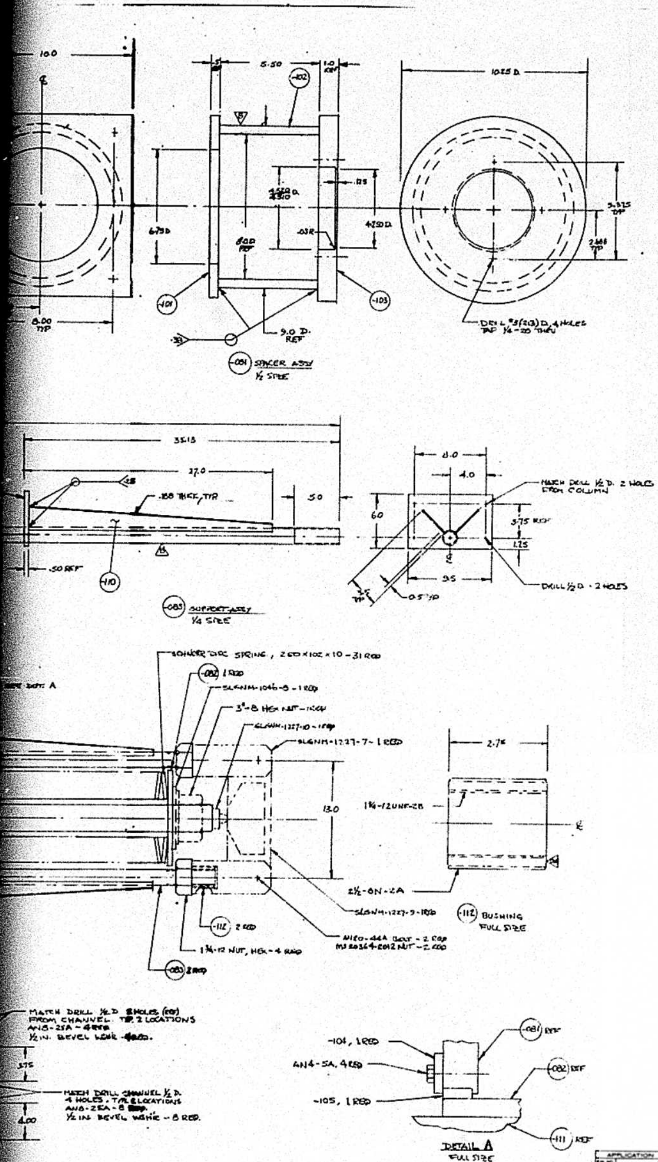

NOTES

1. AFTER WELDING AND BEFORE FINAL MACHINING HEAT TREAT TO 180,000 PSI, RC 39-43
2. BEFORE FINAL MACHINING HEAT TREAT TO 150,000 PSI, RC 34-38
3. MARK PARTS PER SS 8798, △

-083	-082	-081	-011	DASH NO.	NOMENCLATURE	SPECIFICATION	MATERIAL OR NOTE
			31		SCHNORR DISC SPRING	250×102×10	
			1		SLGNM-1083-14	PIN	
			1		" " -20	ADAPTER	
			1		SLGNM-1083-21	NUT	
			1		SLGNM-1046-8		
			1		SLGNM-1227-10		
			2		" " -7		
			1		SLGNM-1227-9		
			12		WASHER, BEVEL	½"	
			12		BOLT	AN8-25A	
			2		BOLT	AN20-44A	
			2		NUT	MS20764-2012	
			1		NUT, HEX	3"-8	STEEL
			4		NUT, HEX	1¾-12	STEEL
			4		BOLT	AN4-54	
			2	-112	BUSHING △	4340 STEEL ANNLD	5 in DIA × 5 in LONG
			1	-111	ROD △	4340 STEEL ANNLD	3 in DIA × 60 in LONG
2				-110	PLATE	4130 NORMALIZED	3/16 × 3½ × 27"
1				-109	PLATE	4130 "	6 in × 7 in × ⅜ THK
1				-108	ROD	4130 "	1.75 DIA × 56.0 in LONG
	1			-107	PLATE	4130 NORMALIZED	12 × 12 × ½ THK
	1			-106	TUBE	4130 NORMALIZED	4⅝ OD × 3.0 ID × 2.50 in LONG
			1	-105	BUSHING	NYLON 101 BAR	4½ OD × 1.0 in LONG
			1	-104	RETAINER	COLD DRAWN STEEL	7.0 × 7.0 × ½ THK
		1		-103	PLATE	" " "	11.0 × 11.0 × 1.0 THK
		1		-102	TUBE	" " "	9.0 OD × 8.0 ID × 6.0 in LONG
		1		-101	PLATE	" " "	10.0 × 10.0 × ½ in THK
			2	-083			
			1	-082	△		
			1	-081	SPACER ASSY		
				-011	INSTALLATION		

LIST OF MATERIAL

APPLICATION OF PROTECTIVE FINISHES
NONE REQ'D

FATIGUE TEST INSTALLATION
PULTRUDED TAIL ROTOR SPAR

FSCM NO. 78286
DRAWING NUMBER EWR 48179

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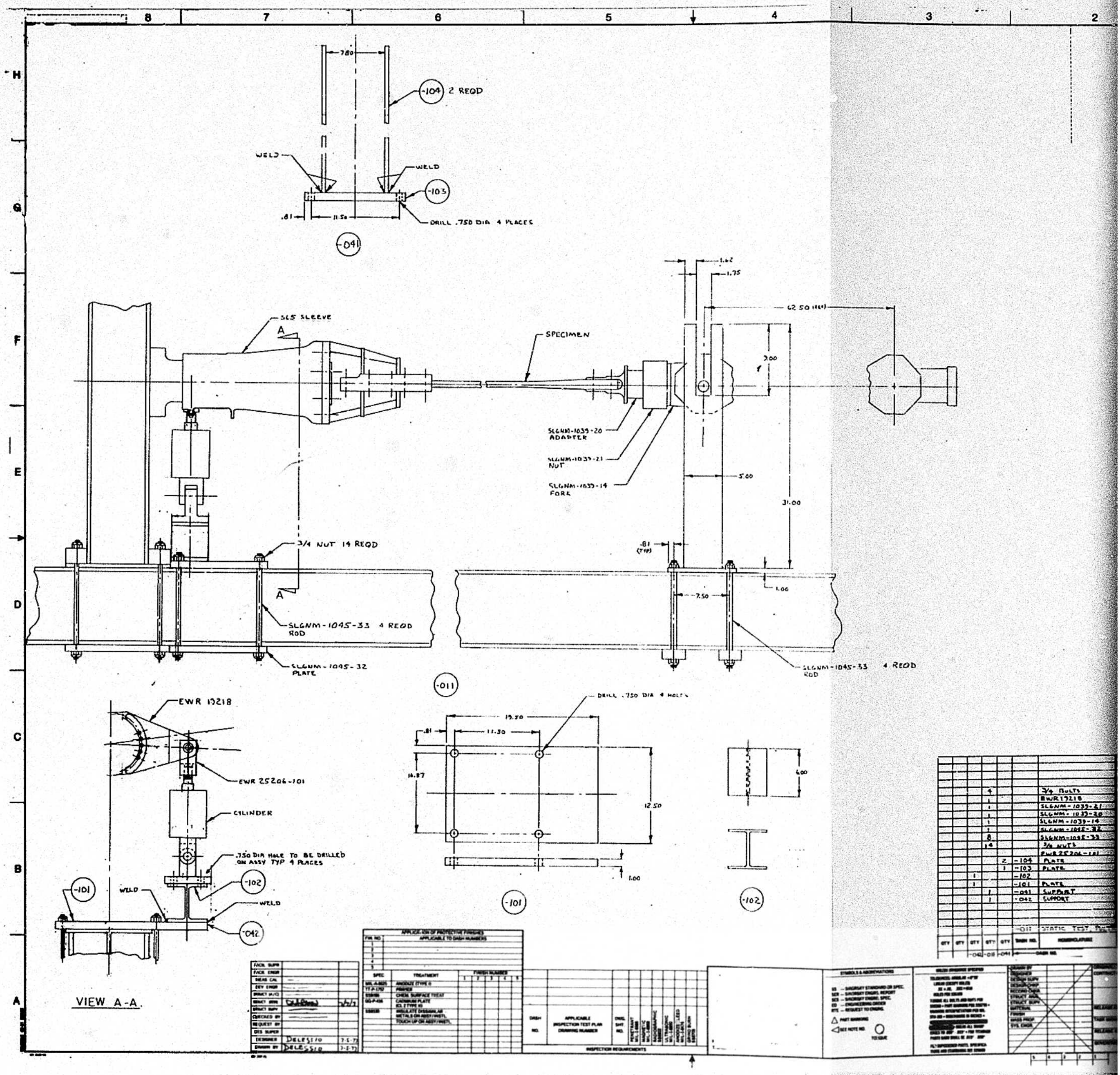

Figure 57. Pultruded Tail Rotor Spar Half Specimen Static Test.

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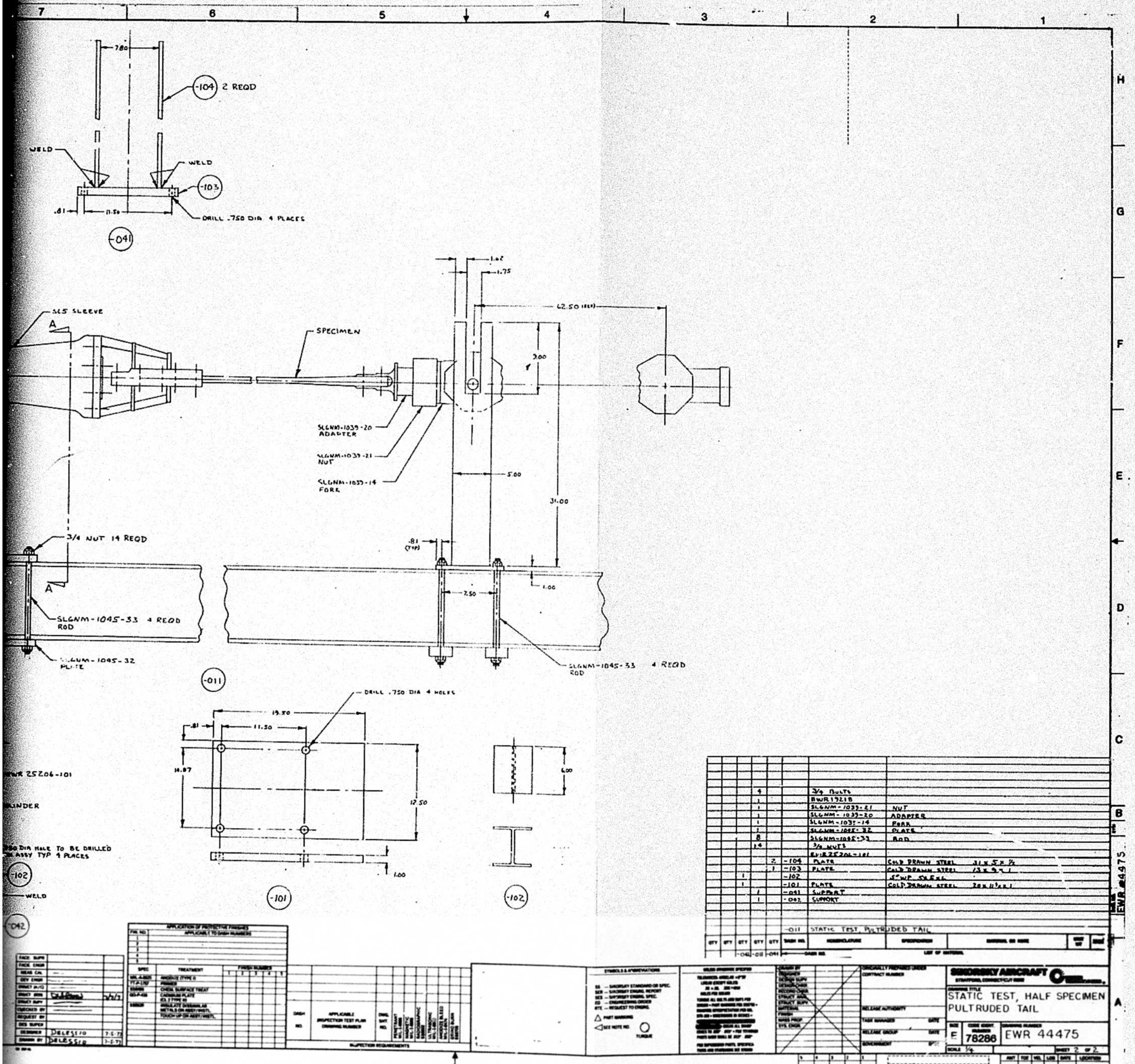

ruded Tail Rotor Spar Half Specimen Static Test.

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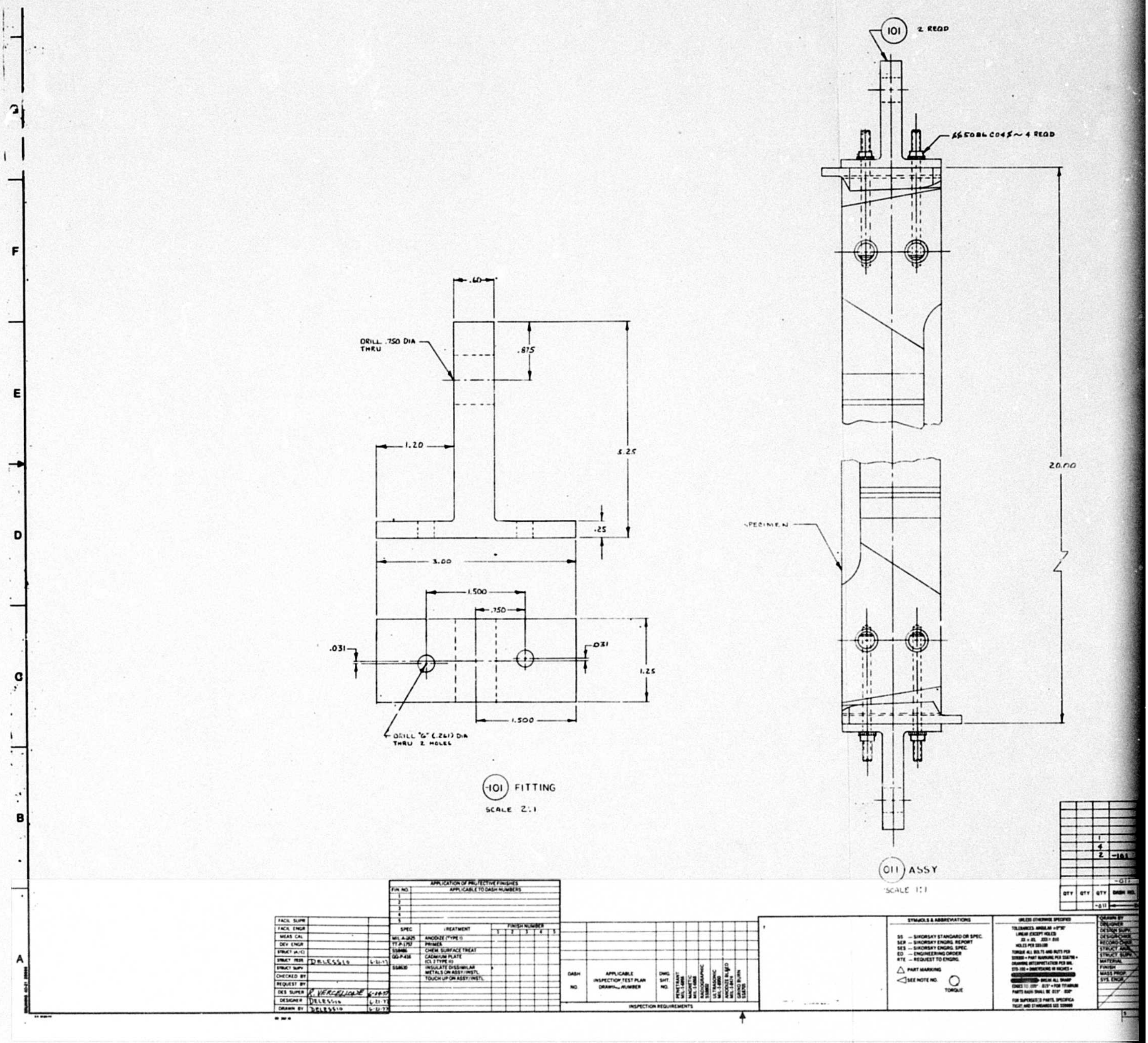

Figure 58. Pultruded Tail Rotor Spar Tip Weight Retention Assembly Static Test.

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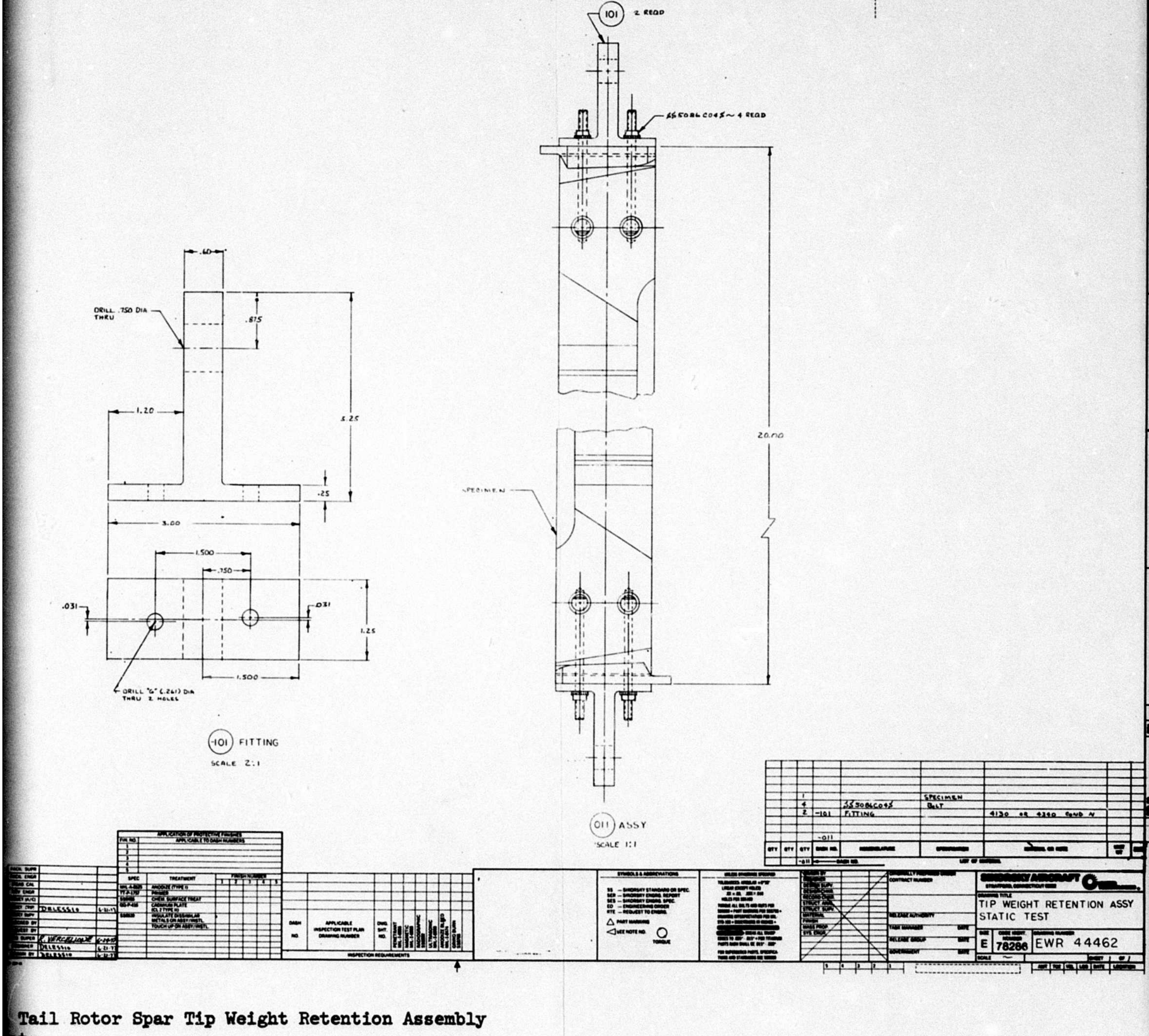

Tail Rotor Spar Tip Weight Retention Assembly
t.

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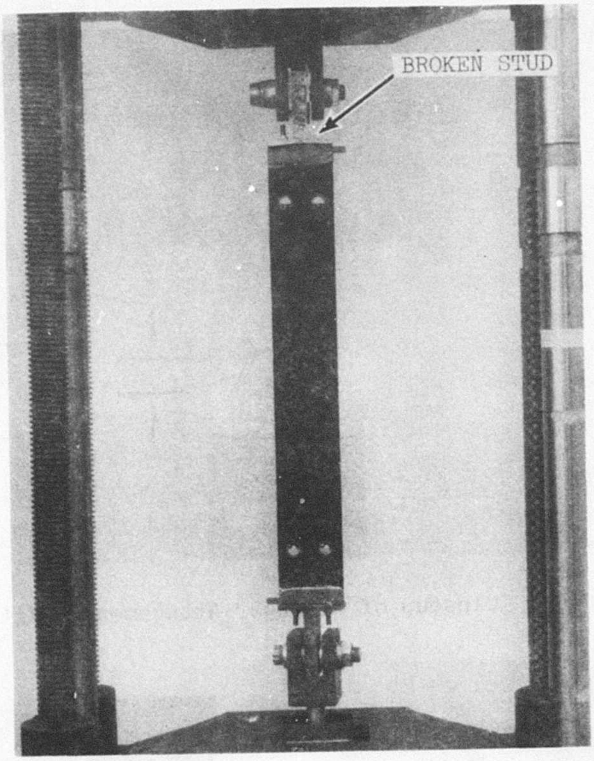


Figure 59. Tip Attachment Specimen, Static Test.

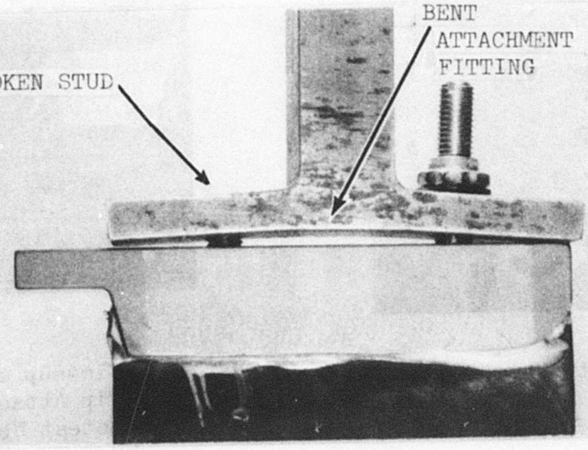


Figure 60. Closeup of Failed Area, Tip Attachment Specimen.
(Note bent test attachment fitting)

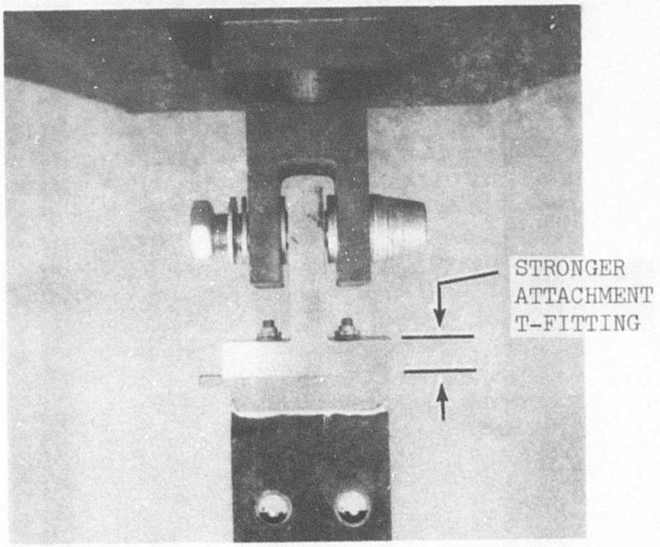


Figure 61. Closeup of Stronger Attachment T-Fitting.

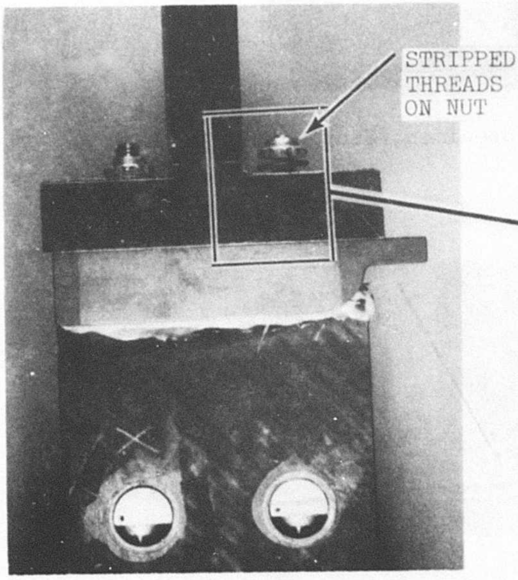


Figure 62. Tip Attachment Specimen After Retest.

Figure 63. Closeup of Failed Area, Tip Attachment Static Retest Specimen. (2X)

(Note that failure mode is different than original)

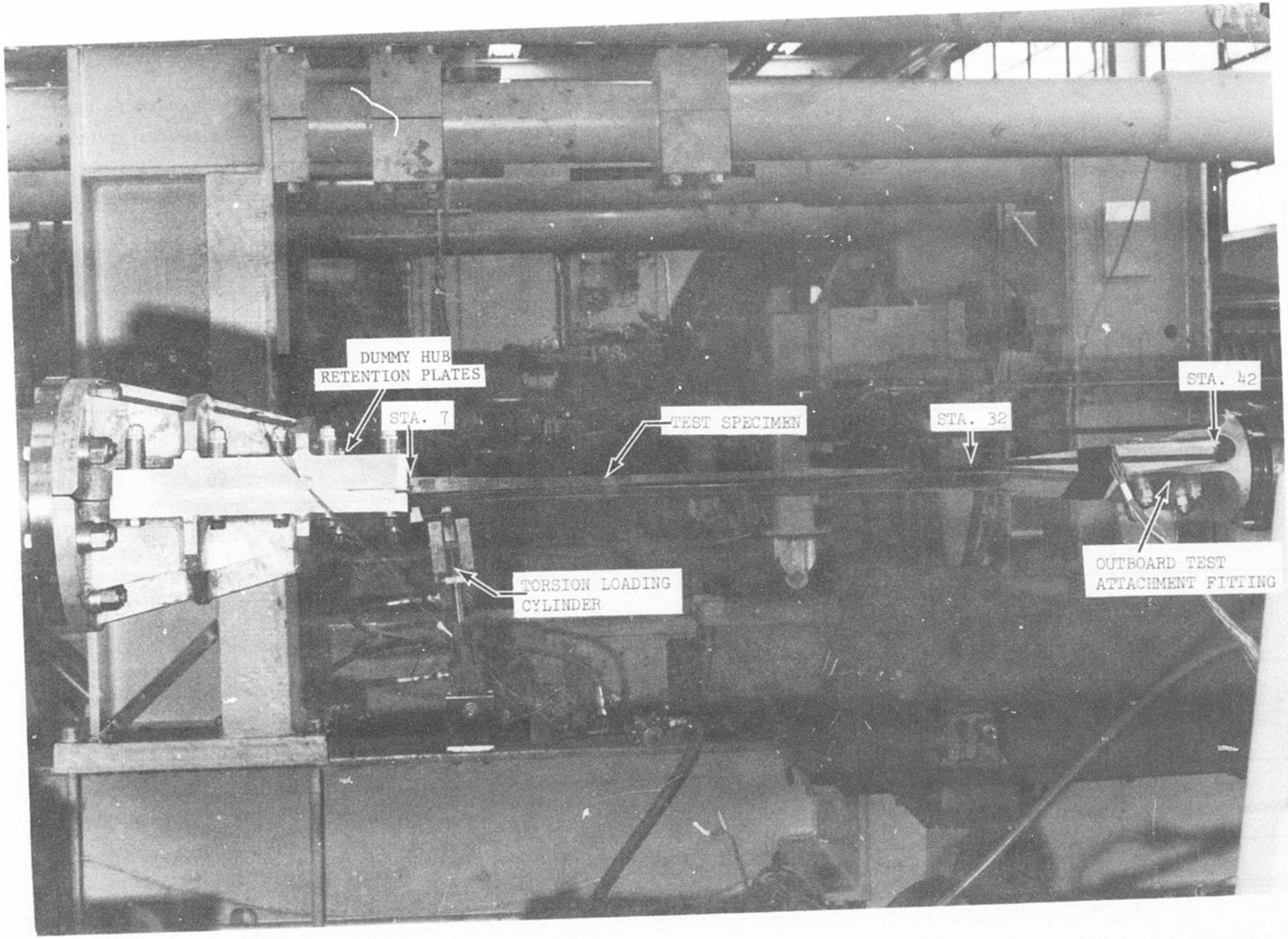


Figure 64. Test Setup of Root End Static Specimen Prior to Loading.

TABLE 14. LOADING CONDITIONS FOR ROOT END STATIC SPECIMEN S/N 6- STATIONS 7.75 AND 28

Conditions	Load Level			
	Axial Centrifugal Load (lb)	Torsional Twist (deg)	Edgewise Moment (in.-lb)	Flatwise Moment (in.-lb)
Original Design Limit Load, Condition 1:				
Sta. 7.75	32,800	10.2	31,000	20,000
Sta. 28	32,800	10.2	10,000	58
2nd Increment:				
Sta. 7.75	34,500	11.6	(a) 32,750	12,100
Sta. 28	34,500	11.6	10,220	68
10th Increment: (b)				
Sta. 7.75	39,000	15.8	28,950	(a) 18,830
Sta. 28	39,000	15.8	8,710	(a) 86
21st Increment: (c)				
Sta. 7.75	49,000	19.3	18,200	(a) 26,890
Sta. 28	49,000	19.3	7,490	74
22nd Flight Loads, Condition 2:				
Sta. 7.75	32,800	10.2	51,700	18,000
Sta. 28	32,800	10.2	18,340	83
26th Fracture, Condition 3:				
Sta. 7.75	35,000	13 approx.	57,860	(a) 22,500
Sta. 28	35,000	13 approx.	21,200	(a) 86

(a) Peak load during condition
(b) End of stroke first time
(c) End of stroke second time

cylinder was obtained. During this initial testing stage, the maximum edgewise load level was obtained on the second increment while the maximum flatwise load level was obtained at the time the cylinder ran out of stroke. (The effective stroke of the cylinder was 7-1/2 inches). The actual loads at these maximum conditions, along with other maximum loads, are provided in Table 14. Figures 65 and 66 show the specimen loaded at the time the cylinder ran out of stroke. The loads were dropped and the cylinder was replaced with a unit of increased stroke. The original design load level was again applied. Load level was increased incrementally until the hydraulic cylinder again ran out of stroke (9-5/8-inch effective stroke). Just prior to the cylinder running out of stroke a sharp "ping" was heard coming from the specimen and/or test facility. The load level at the time the cylinder ran out of stroke is listed in Table 14. The loads were dropped and the cylinder was replaced with a unit of increased capability (13-1/2-inch effective stroke). A revised loading, Condition 2, based on flight measurements, was obtained and the specimen was loaded to this new condition of loads. Bending loads, edgewise and flatwise, were again increased incrementally until fracture (Condition 3, Table 14). Centrifugal and torsional loads were maintained at the levels of Condition 2 after each incremental loading. Figure 67 is a view of the specimen after fracture. Closeup views of the fracture interface are provided in Figure 68. Fracture of the specimen occurred at Stations 28 to 32; reference Figure 69 and Table 14. This region is in the constant section (0° fiber orientation) area of the spar specimen, 4 inches beyond the end of the taper. The fracture location coincides with an ultrasonic indication observed during ultrasonic inspection at 38dB sensitivity (see Figure 70). 38dB and other associated settings correspond to the current acceptance standard for the production spar; i.e., no ultrasonic indications are permitted at this level. This nondestructive inspection, based on NDI acceptance criteria, was not used for the prototype YUH-60A spars and was not considered cause for rejection of the pultruded spar. No ultrasonic acceptance requirements were established for the pultruded spar specimen.

Short beam shear specimens taken from the adjacent areas, Stations 43 to 44, prior to static testing showed satisfactory shear strength of 13,000 to 15,000 psi, well above the 11,000 psi minimum requirements.

Static Root End Evaluation. In an effort to determine more definitively the cause of fracture at Stations 28 to 32, analyses of the test data, test conditions, and material were performed. Results of the analysis of the test data and test conditions revealed no abnormal factors that contributed to the premature fracturing of the spar specimen at the Station 28 to 32 location; i.e., the critical section is analytically predicted to be at Station 7.75. Macro- and micro-examination of cross sections confirmed that the ultrasonic indications were local dry, unwetted fiber areas as depicted in Figure 70. Short beam interlaminar shear test specimens were sectioned from several locations in the pultrusion material portion of the spar specimen and subsequently tested. The shear specimens were taken from areas in and adjacent to the dry fiber areas observed in

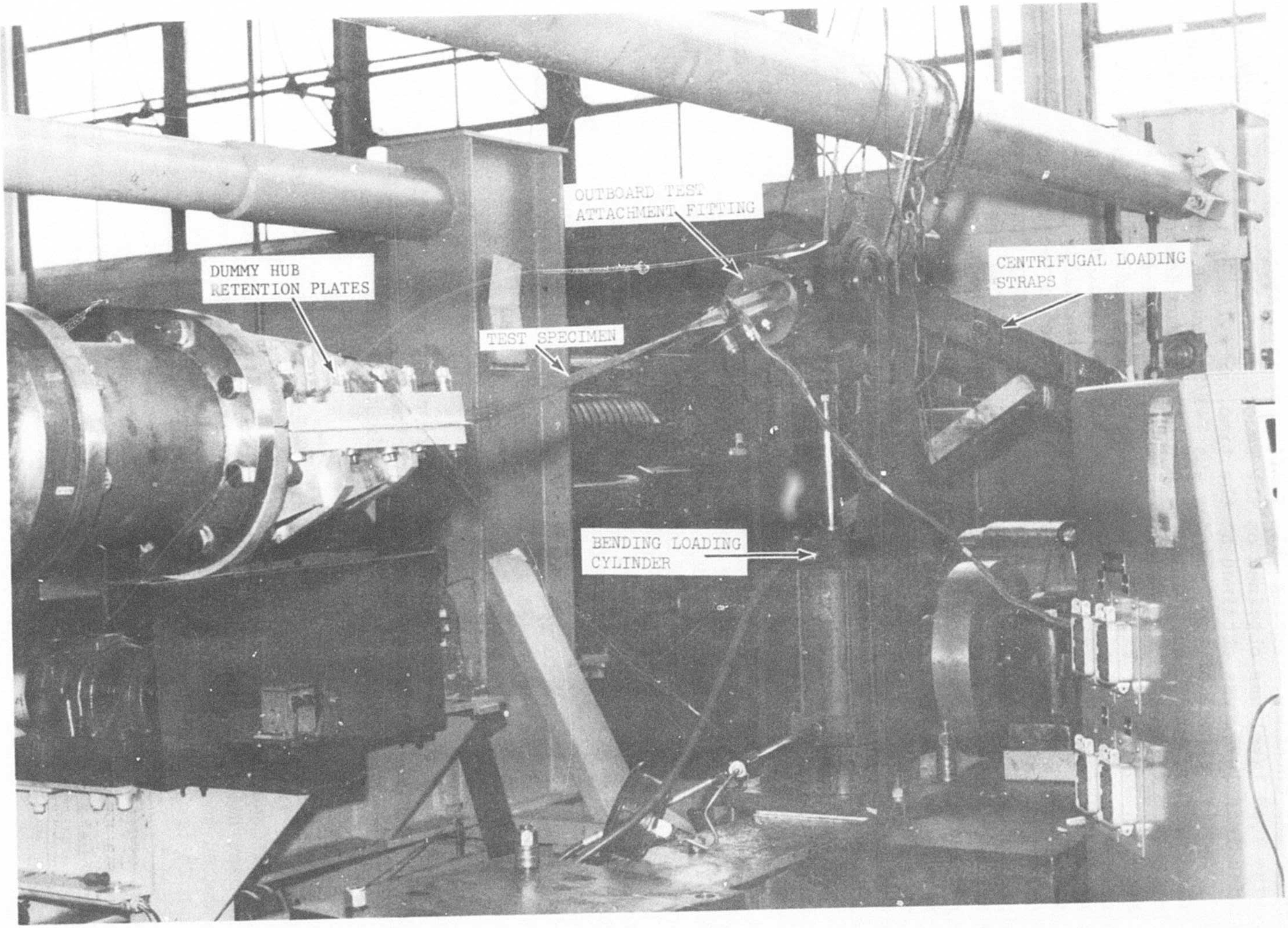


Figure 65. Root End Static Test Specimen With Load Applied to Condition 1, View A.

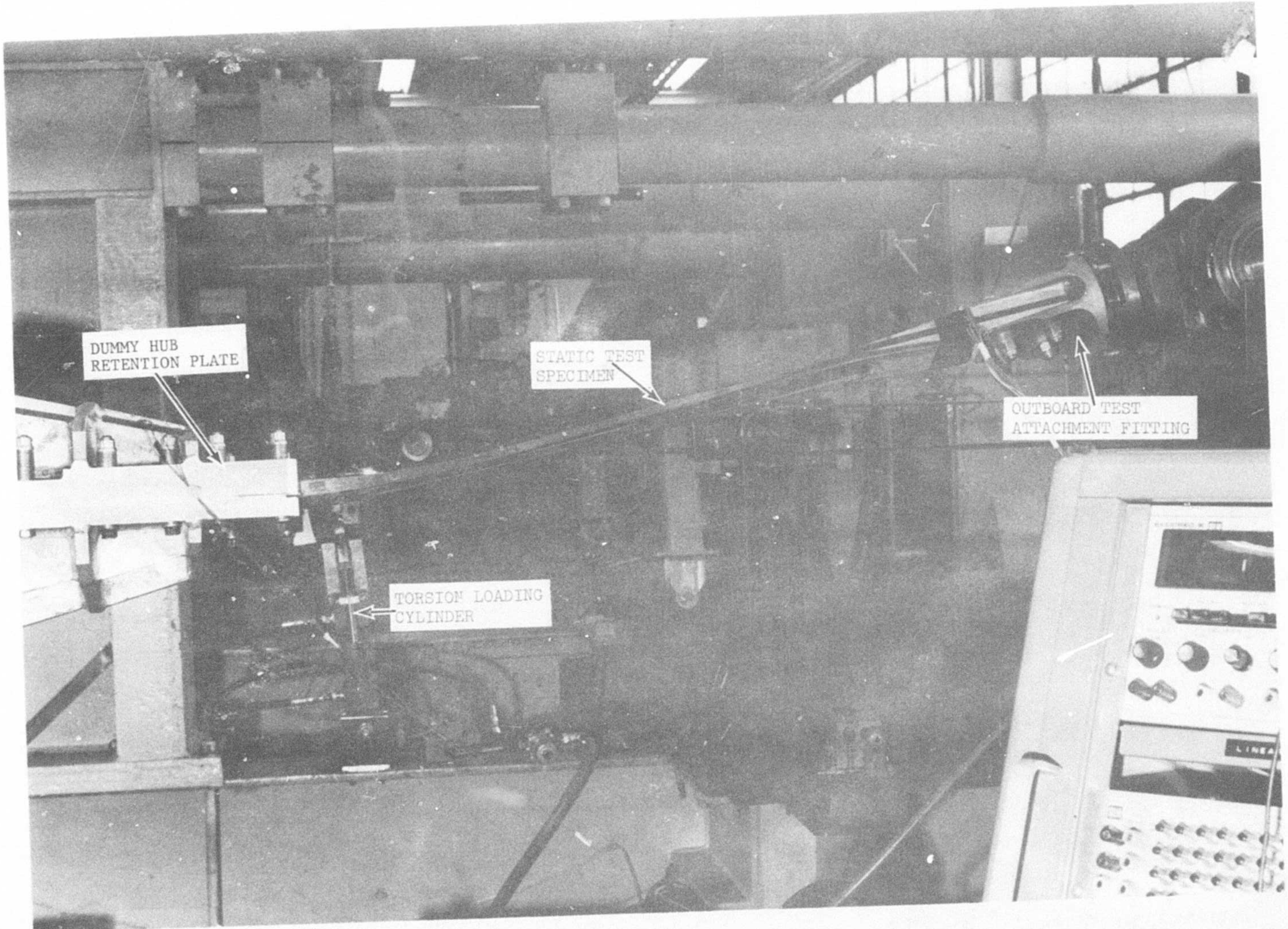


Figure 66. Root End Static Test Specimen With Load Applied to Condition 1, View B.

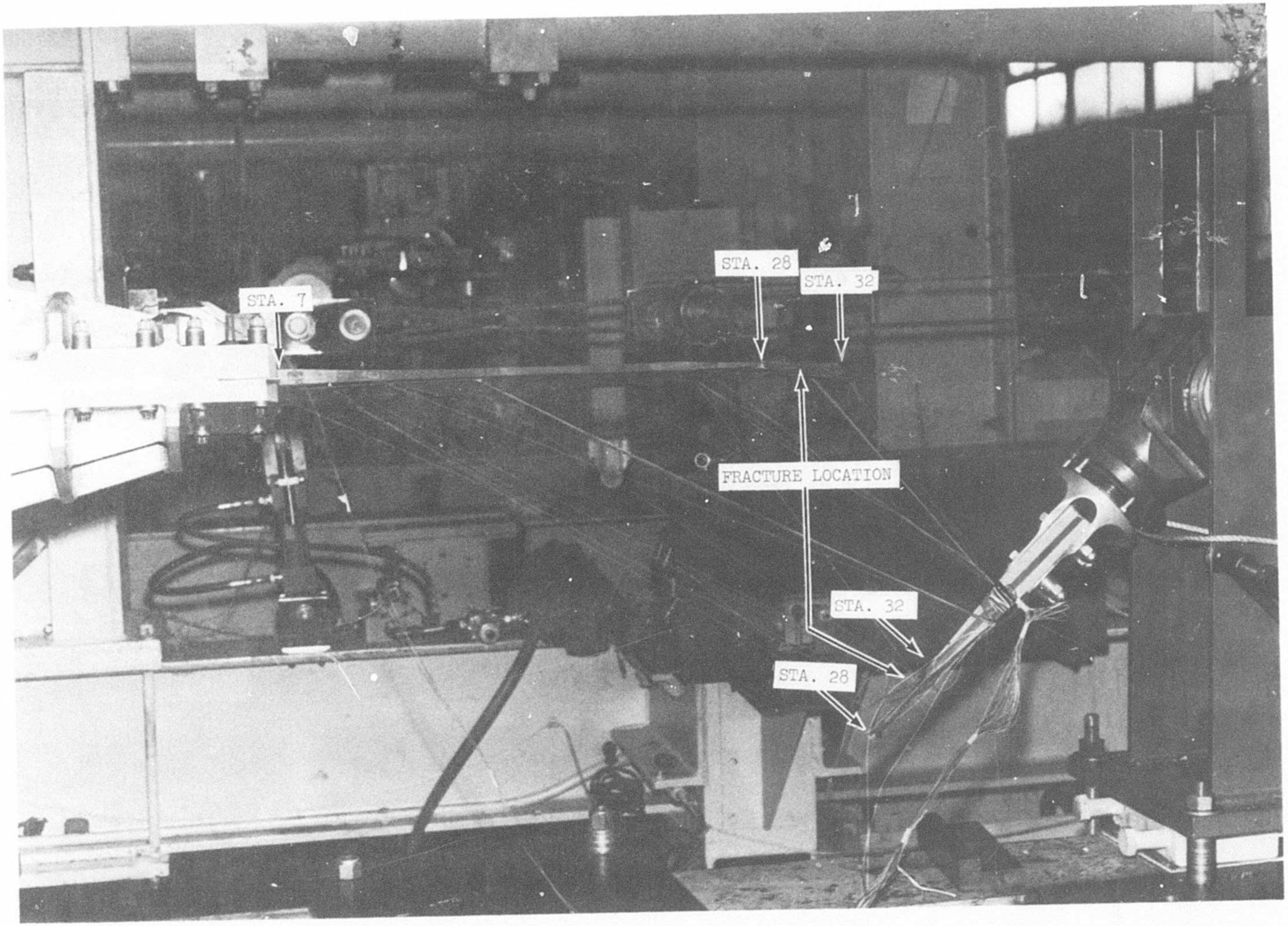


Figure 67. Root End Static Test Specimen, Fractured.

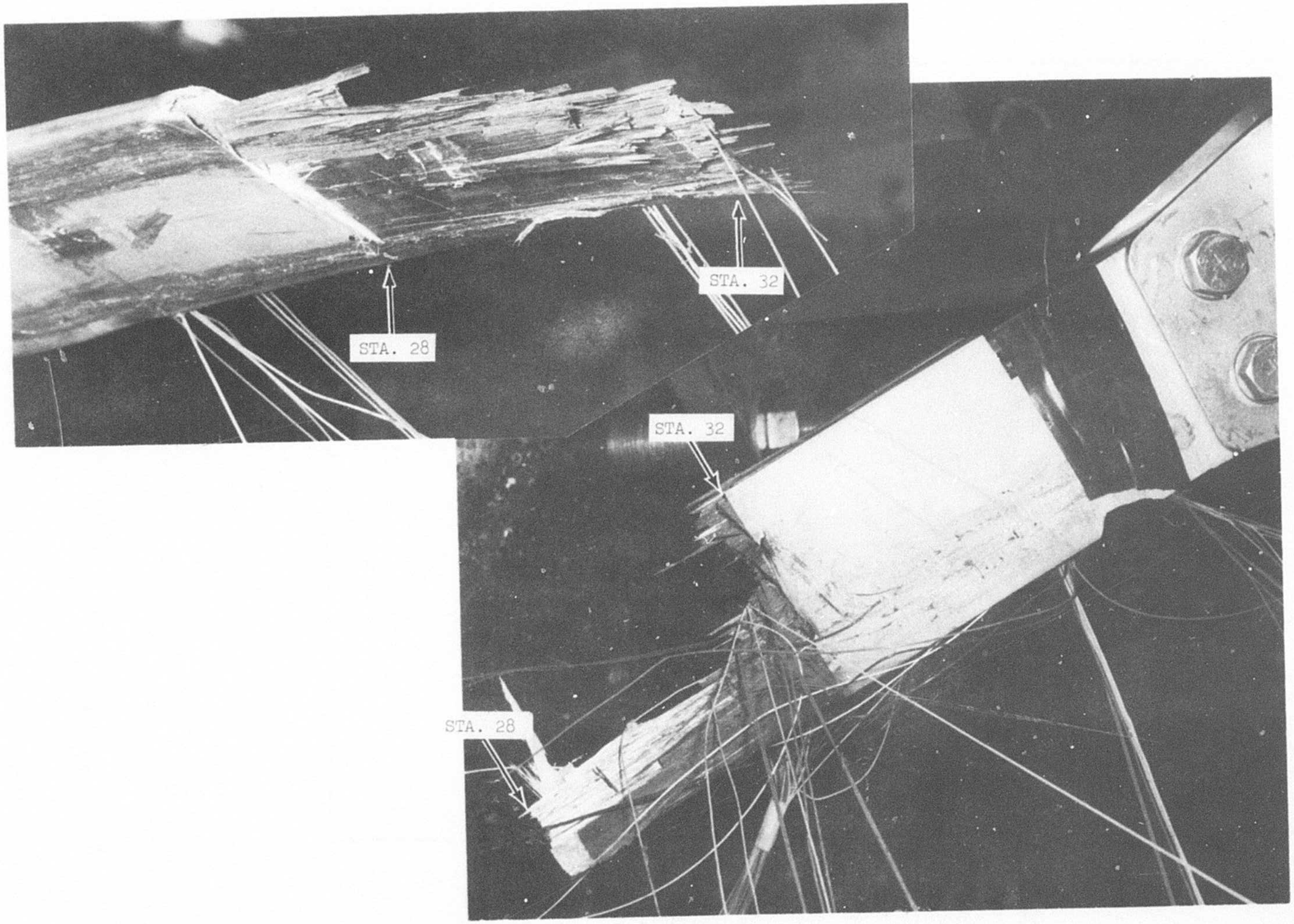


Figure 68. Closeup of Root End Static Test Specimen Fracture.

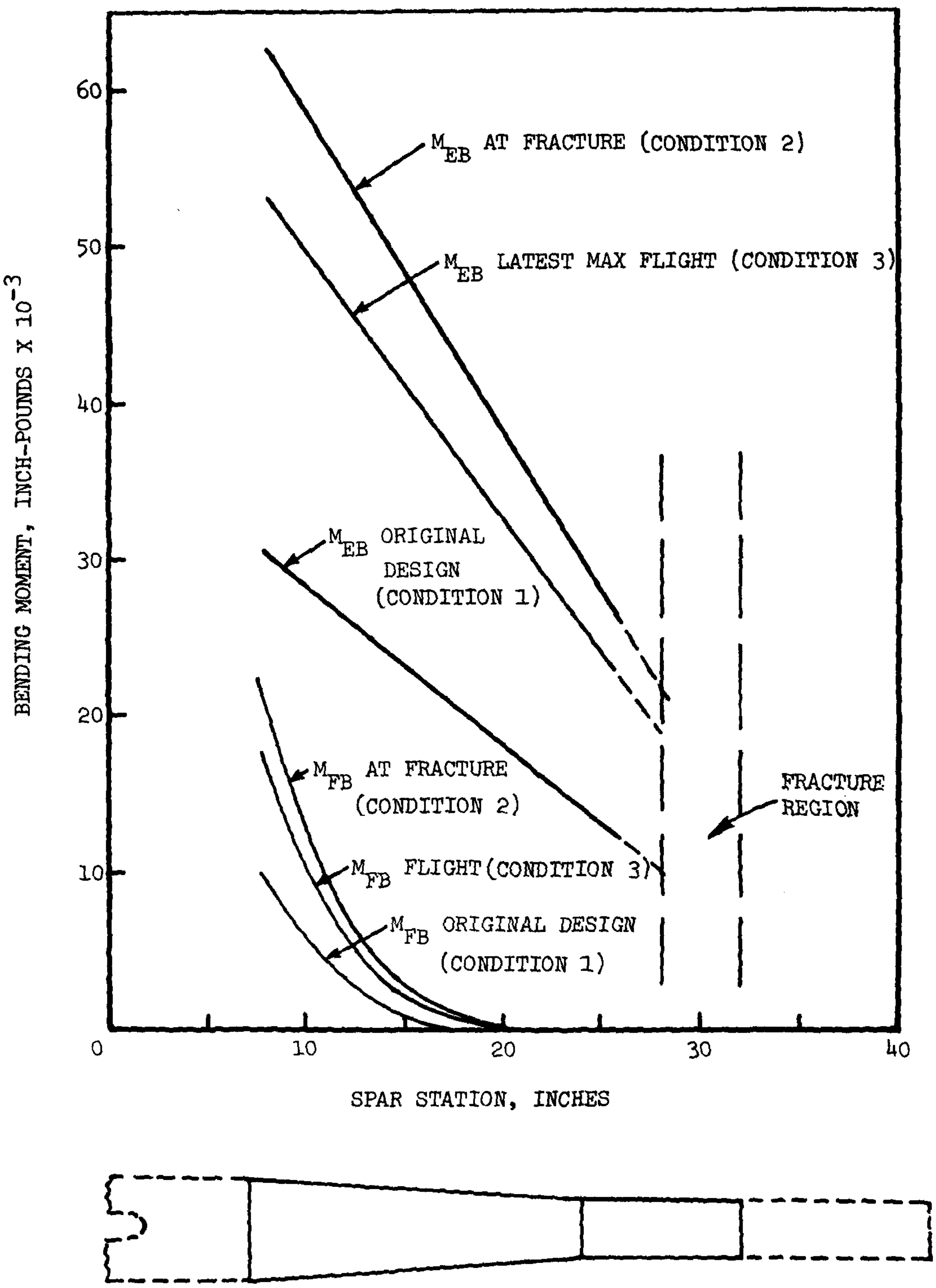


Figure 69. Pultruded Tail Rotor Spar Static Test Bending Moment Distributions.

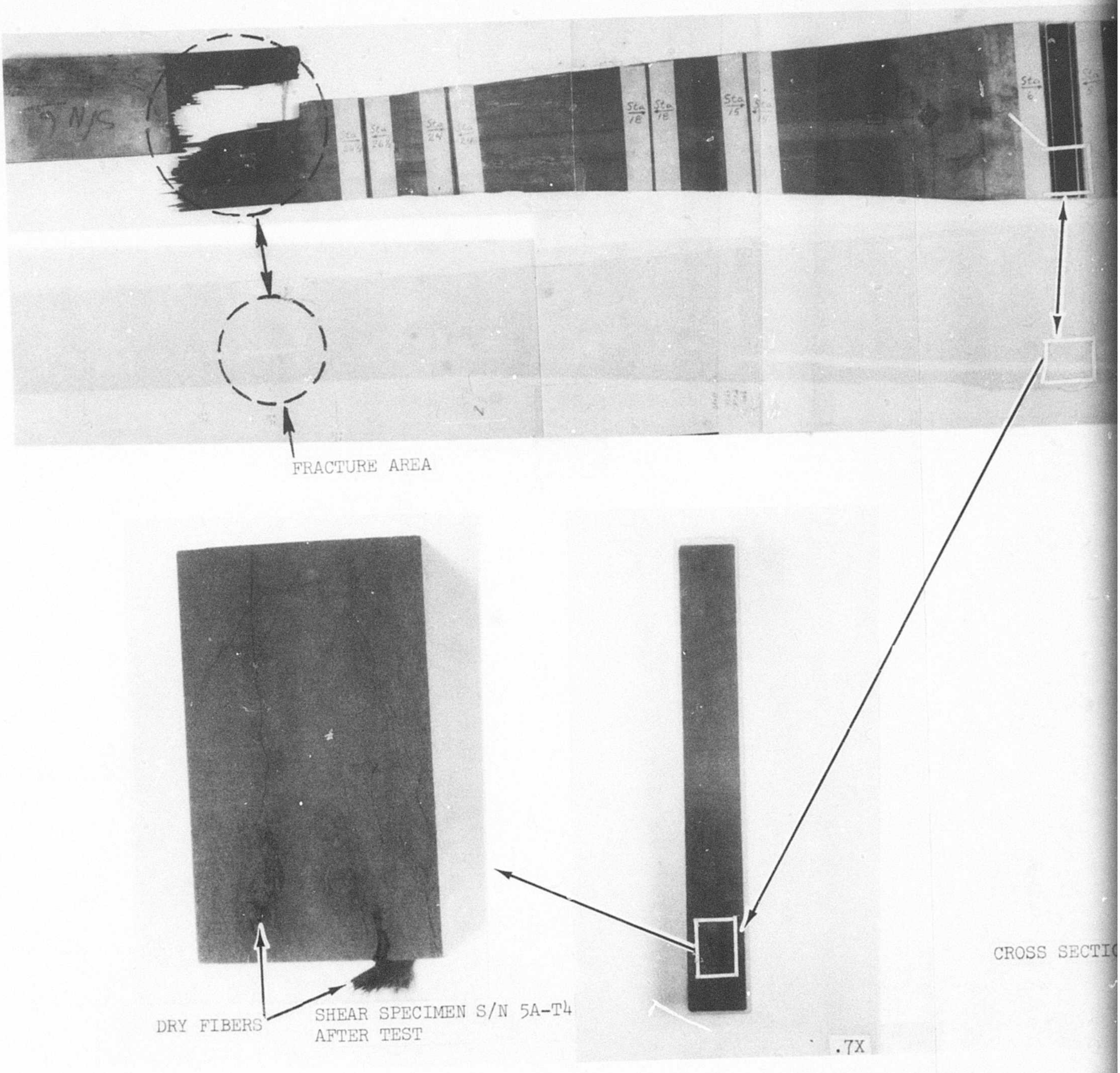
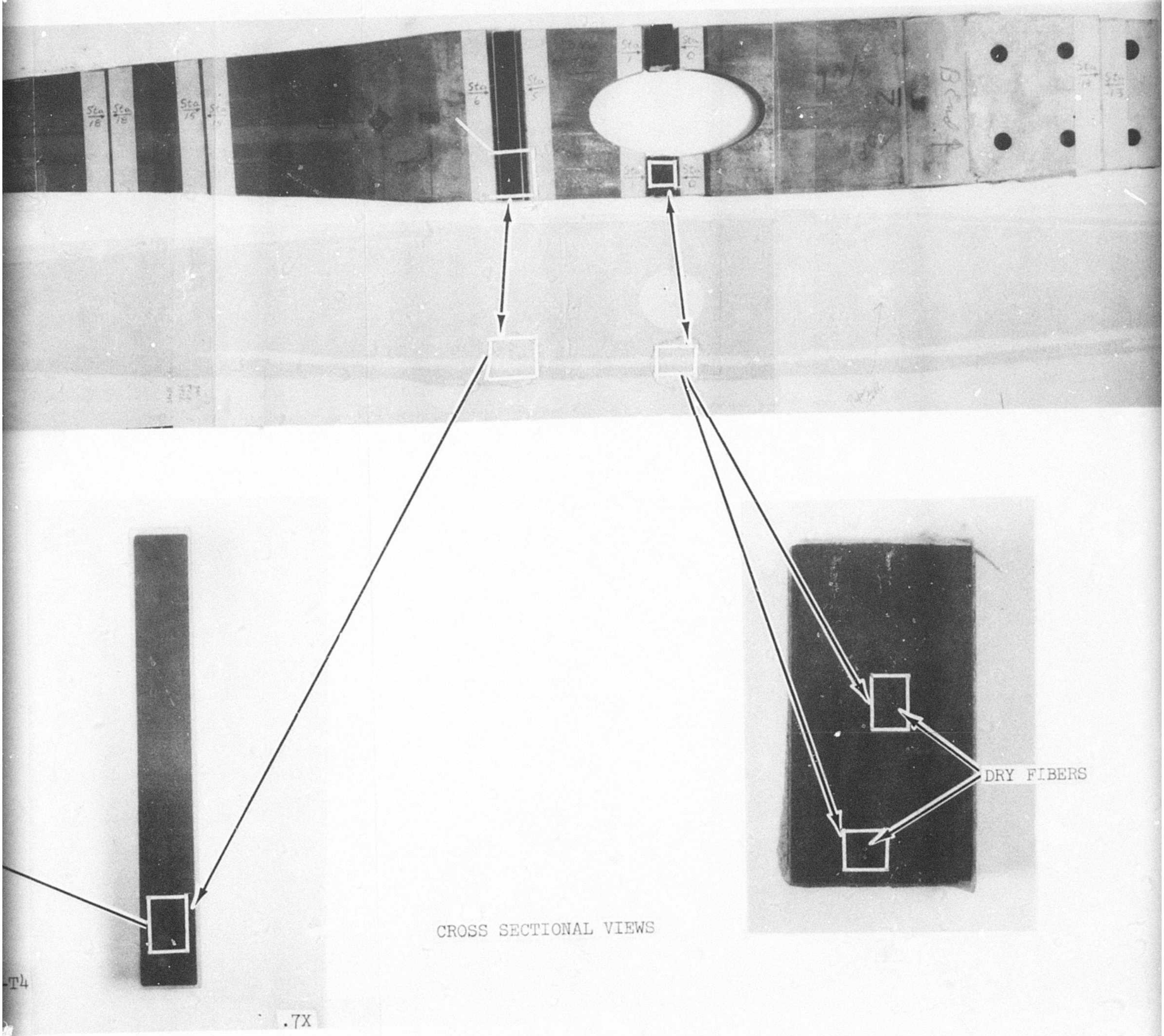


Figure 70. Static Test Specimen With Ultrasonic C-scan Recording and Cross Sections Depicting Indications of Dry Fibers in Pultrusion Material.



rasonic C-scan Recording and Cross
Fibers in Pultrusion Material.

the ultrasonic C-scan recordings. The results indicate that the pultruded material typically exceeded the specification minimum of 11,000 psi by 2,000 to 4,000 psi. The only exceptions are those specimens that contain dry fibers and subsequently have values as low as 10,000 psi. The lowest value specimen was the one that was subsize and contained a greater percentage of dry fibers with respect to the cross sectioned area. Theoretically, the shear strength of the dry fiber area would be 0 if a small enough specimen could be made, i.e., the specimen would fall apart.

To eliminate the possibility of dry fibers existing in the production pultruded design, two changes were intended to be incorporated: (1) 1.5-inch-wide sections were to be pultruded rather than a 3.0-inch-wide section. This was to allow better fiber wetting by enabling the spooling of 19 bundles of 10,000-filament/tow AS graphite on each of the existing 20 spools instead of 38 bundles/spoil as previously utilized. (2) The production NDI ultrasonic C-scan inspection and acceptance criteria were to be incorporated into pultrusion NDI acceptance criteria.

Static Root End Stress Analysis. As shown in Figure 71 and as previously discussed, the static fracture occurred at a test condition that exceeded the original design conditions for the prototype (UTTAS) and pultruded spar. However, the load level was lower than the new 1.5X limit load design condition used for the production BLACK HAWK spar designs. The pultruded spar stress analysis had predicted positive margins with the original design load condition. The initial effort, therefore, was to analyze the current pultruded spar design using the new production BLACK HAWK spar loads.

Figure 72 summarizes the basic analysis, which assumes a homogeneous spar. The "Hill Criterion" was used to combine bending, axial, in-plane and interlaminar shear stresses to predict the margin of safety. The analysis indicates that the pultruded spar shows a minimum margin of safety (MS) of + 0.01 at Station 23. The following allowables were used in the analysis: ultimate flexure strength - 180 ksi, ultimate tensile strength - 160 ksi, and ultimate interlaminar shear - 10 ksi. If the flight axial and shear stress distribution are duplicated in the lab for the new 1.5X limit load condition, the specimen would not have been predicted to fail. Nonfailure of the specimen would have been anticipated because the allowables used were reduced from typical small specimen mean strengths. Some differences in the actual axial and shear stresses do exist due to the different method of introducing loads between in-flight and static test. For this reason, and because a loud noise was heard emitting from the test specimen during load increment #21 (a high centrifugal force, high torsional twist, low edgewise moment condition), both the fracture condition (load increment #26) and the load increment #21 conditions were also analyzed to determine if a fracture could have been predicted. Details of the loading and unloading sequences and reasons for the sequences were reported previously in Table 14. The actual load distributions attained for increments #21 and #26 (the fracture condition) and for the new 1.5X limit load design condition are shown in Figure 73. The calculated axial and shear stresses and margins of safety versus span are shown in Figure 74 along

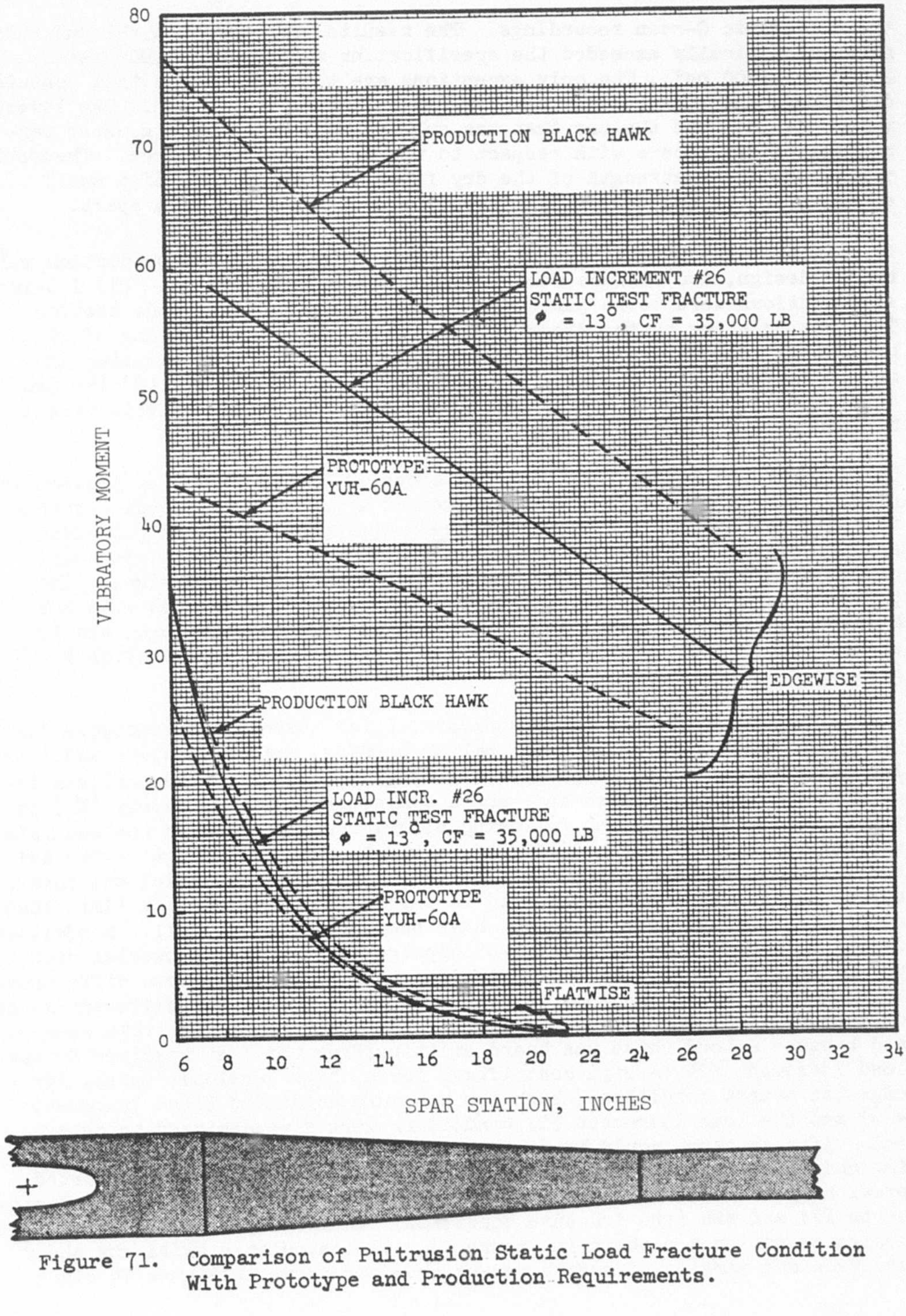


Figure 71. Comparison of Pultrusion Static Load Fracture Condition With Prototype and Production Requirements.

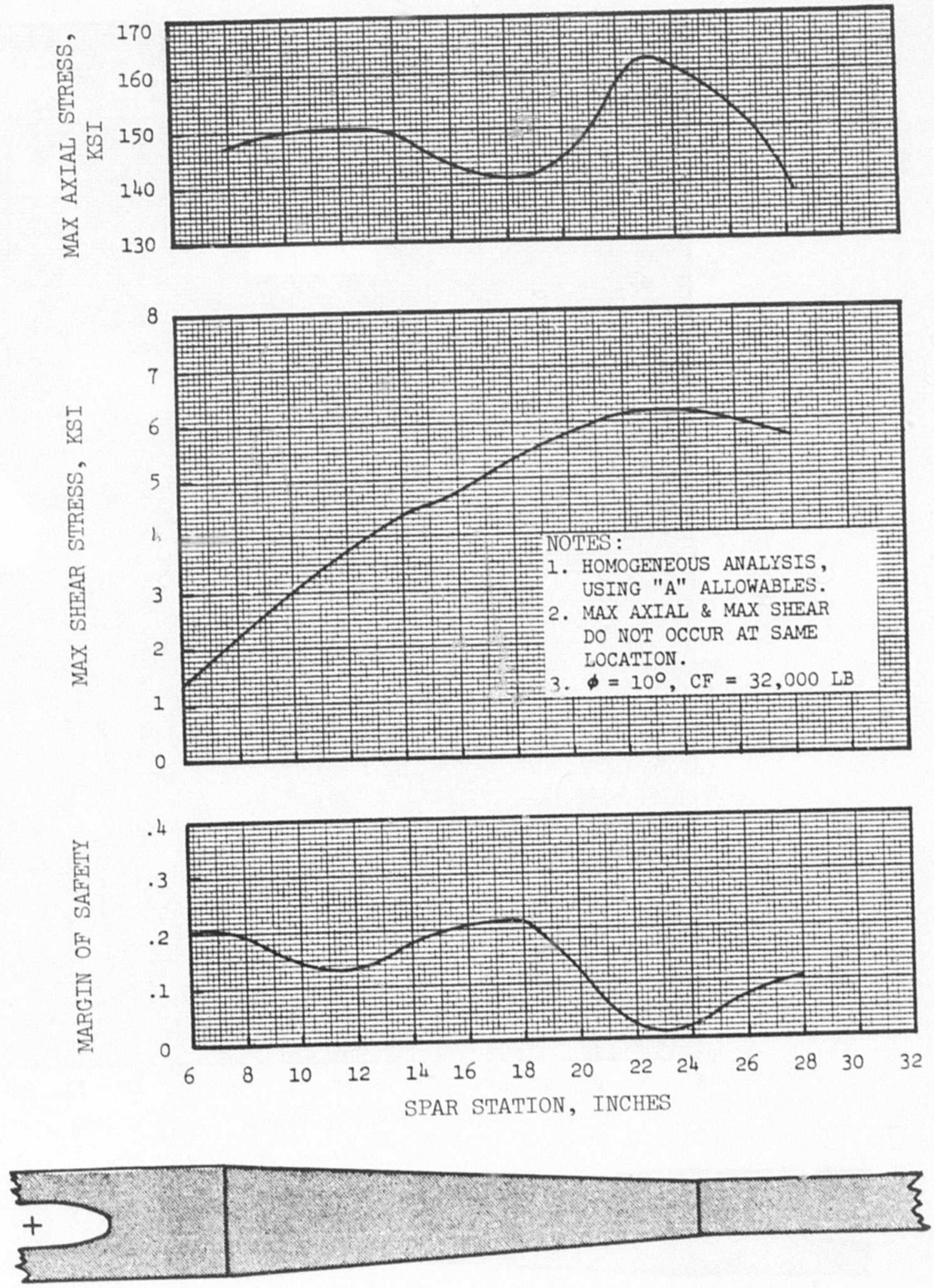


Figure 72. Maximum Axial Shear Stress and Calculated Margin of Safety for Pultruded Spar Design.

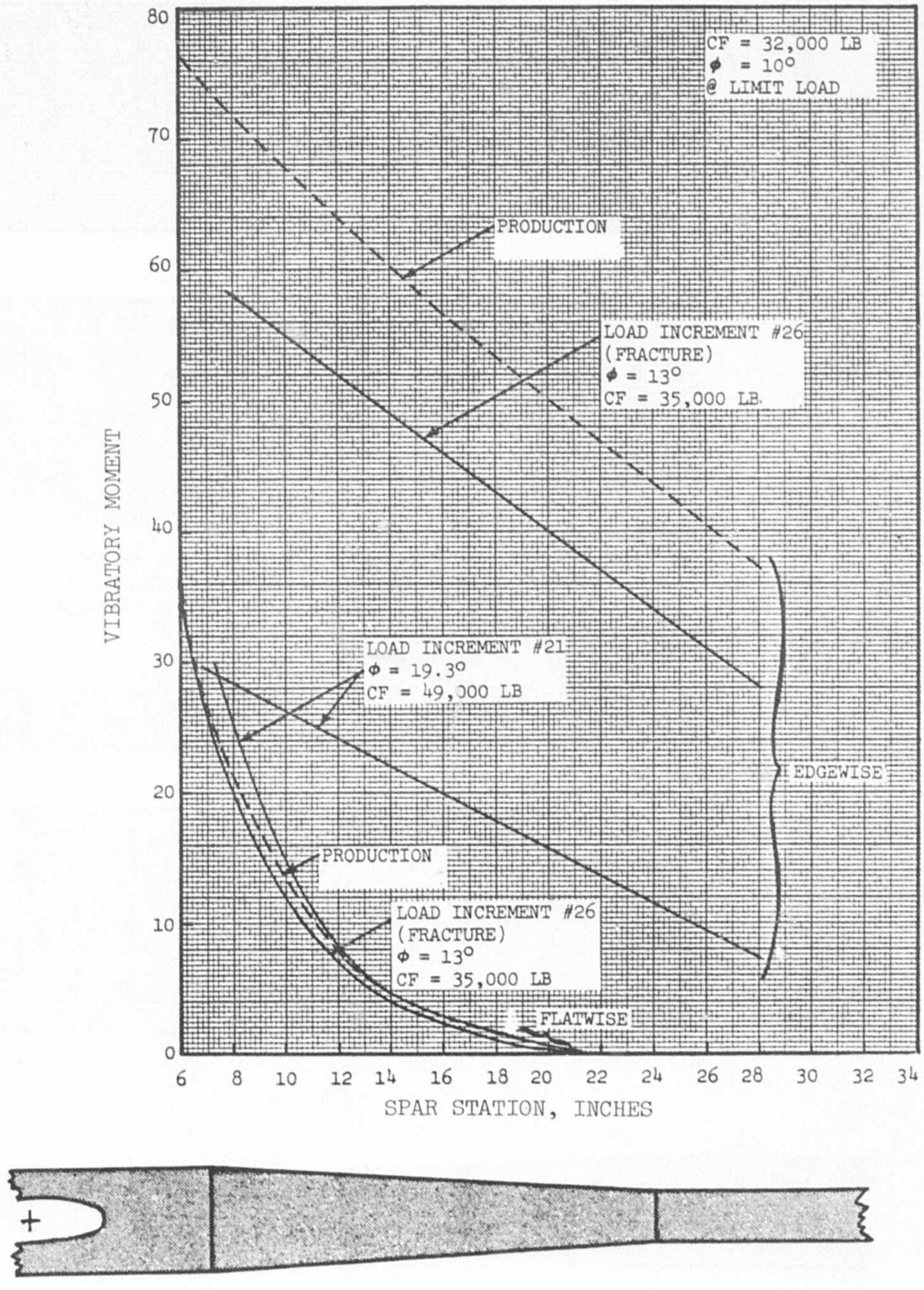


Figure 73. Comparison of Static Load Conditions 21 and 26 (Fracture) With Production 1.5X Limit Loads.

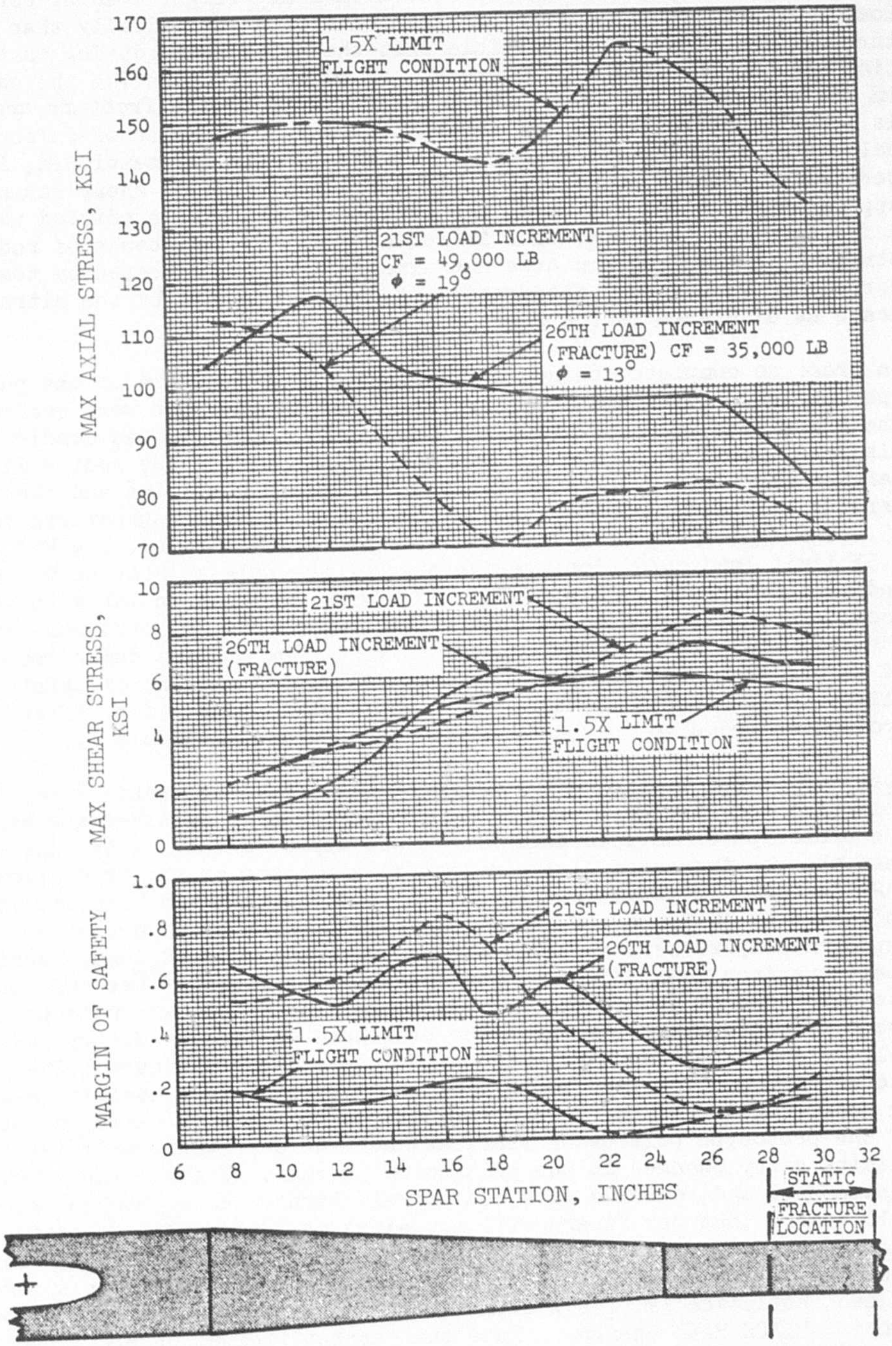


Figure 74. Comparison of Maximum Axial and Shear Stress, and Calculated Margins of Safety for 1.5X Limit Load.

with the previous prediction for the 1.5X limit flight loading condition. Load increment #21 is a more critical condition analytically than the fracture condition and it is possible that the noise heard during that condition was the initiation of a crack. As shown in Figure 74, the calculated MS for increment #21 is + 0.08 in the vicinity of the fracture area and is largely controlled by the shear stresses. The margin of safety was calculated assuming the allowable stresses previously mentioned, i.e., interlaminar shear = 10 ksi, etc. If a reduced value of shear stress of approximately 9 ksi was used, the analysis would have predicted MS = 0 or a fracture for test condition increment #21. The existence of reduced shear strength in the fracture area has already been demonstrated by test and correlated with visual observation of dry fibers, and by the ultrasonic C-scans as discussed in the previous section.

In order to complete the new higher static load analysis of the pultruded spar design, additional lap shear and laminate analyses were conducted. These analyses were performed for the flight and test load conditions at discrete locations or change in cross-section within the root buildup. The margins of safety calculated for the new design condition and the minimum margins of safety demonstrated by the static test are summarized in Table 15. The additional locations shown to be critical (i.e., low MS) for the 1.5X limit load condition are the edge of the hole at Station 0, and the end of the torpedo at Station 24. However, as shown in Table 15, these locations have been demonstrated by test to exceed the strength required for the 1.5X limit load design condition, i.e., the minimum demonstrated margins of safety from test are less than the calculated margins of safety for the flight design load condition. This includes the analytical effect of the production redesign in the root area as indicated in Table 15.

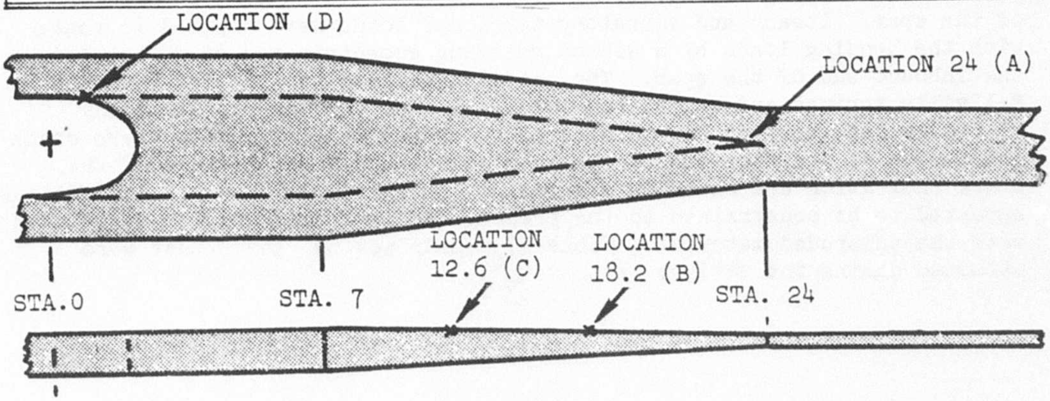
<u>Static Root End Testing and Evaluation Summary</u>. The static strength of the pultruded spar design exceeded the original design requirements based on the prototype UTTAS spar design, but was approximately 10 percent lower than the new increased ultimate load requirements of the production BLACK HAWK design. The spar fractured at a location that had been analytically indicated as having a low margin of safety. However, fracture occurred approximately 20 percent below the calculated predicted load, based on small specimen mean strength static data. The fracture was influenced by the existence of dry fibers at the fracture location, which reduced the shear strength significantly. The existence of the dry fibers was detectable by current production ultrasonic inspection techniques. The subject static root end specimen would have been rejected if a specific requirement or understanding of the C-scan indications had been in existence at the time of the prototype pultrusion fabrication. The dry fiber condition can be eliminated by changes in the pultrusion process. These changes have been implemented and, coupled with additional ultrasonic acceptance criteria, will assure that dry fibers will not exist in future test or production pultruded spars. Elimination of the dry fiber condition and the resulting increase in shear strength will allow the pultruded spar root end design to exceed, analytically, the increased ultimate load requirements of the production BLACK HAWK design. Since the current production BLACK HAWK design is only required to be substantiated analytically, additional static tests of the pultruded root end design are not required.

TABLE 15. SUMMARY OF CALCULATED MARGINS OF SAFETY FOR PULTRUDED SPAR DESIGN

	Location	1.5X Limit Flight Load Condition (production) ⓐ	Load Incr. #21, High C.F. ⓐ	Load Incr. #26 (fracture) ⓐ
Homogeneous Analysis	Sta. 22-26 (from Figure 3)	0.01	0.01	0.24
Lap Shear + Laminate Analysis (see sketch)	Sta. 24(A) (end of torpedo)	0.11	-0.02	0.02
	Sta. 12.6(C) @ doubler ply	0.52	0.90	1.41
	Sta. 18.2(B) @ doubler ply	0.86	3.0	0.68
	Sta. 0 (D) @ edge of hole	-0.03 ⓑ	-0.01	0.35

ⓐ Material Allowables used in Analysis
Flex Strength = 180 ksi
Tensile Strength = 160 ksi
Interlaminar Shear = 10 ksi

ⓑ Redesigned production spar has increased graphite-epoxy thickness in this region (from 0.590 in. thick to 0.640 in. thick). MS for redesigned pultruded spar would be + 0.23.



Fatigue Root End Test and Evaluation

Fatigue Root End Testing. The fatigue test of the root end was conducted on spar specimen S/N 7 as part of the program to verify the structural adequacy of the pultruded tail rotor spar. Actual testing was conducted in the same 40,000-pound blade test facility as was used for the static testing. The spar was instrumented with strain gauges using a similar technique and procedure to that employed previously. The strain gauges were calibrated by the incremental application of known moments as performed previously.

Fatigue testing of the root end specimen was accomplished by incorporating the flight load conditions into the actual testing. The test loading conditions directly correlate to actual flight loads and to the actual test conditions that will be employed for testing the production BLACK HAWK tail rotor spars. These loading conditions were an increase from the original loading conditions and are shown in Table 16. Analytical analysis of the pultruded test specimen setup with the incorporation of the higher, more severe revised loading conditions was performed. As anticipated, the results revealed the necessity for the incorporation of a softer material between the top and bottom surfaces of the spar specimens and the faying surfaces of the aluminum retention plates on the test facility. This system is similar to the assembly condition incorporated in the production design. Subsequently the dummy hub aluminum retention plate was reworked by machining a rectangular slot into the faying surfaces of each half-segment of the aluminum retention plates. The machining was performed in order that a 0.120-inch-thick nylon-epoxy pad or shim could be inserted into the machined rectangular panels and bonded in place.

Following the modifications to the testing facility, the fatigue test spar specimen was installed and testing performed. Figure 75 depicts the fatigue test setup in which the test spar specimen was installed. The spar specimen was fixed in position in the test facility. The root end of the specimen was secured to a vertical beam of the test facility at a predetermined angle while the outboard end of the specimen was secured to the centrifugal loading straps by means of a pin attachment. The edgewise and flatwise vibratory bending moments were applied in a cantilever mode by means of a rotating eccentric and crank arm located at the outboard end of the spar. Steady and vibratory torsional loads were applied in phase with the bending loads by a second rotating eccentric and crank located at the inboard end of the spar. The centrifugal load was applied by means of Bellville springs and calibrated loading straps. After approximately 30,000 cycles, testing was terminated following an interlaminar-type crack indication at the root end of the spar specimen. Several views of the crack indication are shown in Figures 76 through 79. The crack indications appeared to be constrained to the prepreg doubler plies and not associated with the pultruded material. Table 17 summarizes the loads that were attained during the fatigue test.

TABLE 16. SUMMARY OF FATIGUE TEST CONDITIONS AT STATION 7.75

	Original Test Plan		Revised Conditions Based on Latest Flight Measurements	
	Original Predicted Loads	Originally Proposed Fatigue Test Conditions	New Flight Measured Loads	New Proposed Fatigue Test Conditions
Steady Centrifugal Load (lb) @ (100% N_R)	21,000	21,000	21,000	21,000
Edgewise Moment				
Steady (in.-lb)	1,000	1,000	2,700	0
Vibratory (± in.-lb)	5,900	10,000	8,000	16,000
Flatwise Moment				
Steady (in.-lb)	1,200	1,200	1.950	0
Vibratory (± in.-lb)	5,400	9,200	7,000	14,000
Torsion				
Steady (degrees)	7	7	5	5
Vibratory (± degrees)	4	6.8	3.75	7.5
Acceleration Factor for Vibratory Loads	1.0X	1.7X	1.0X	2.0X

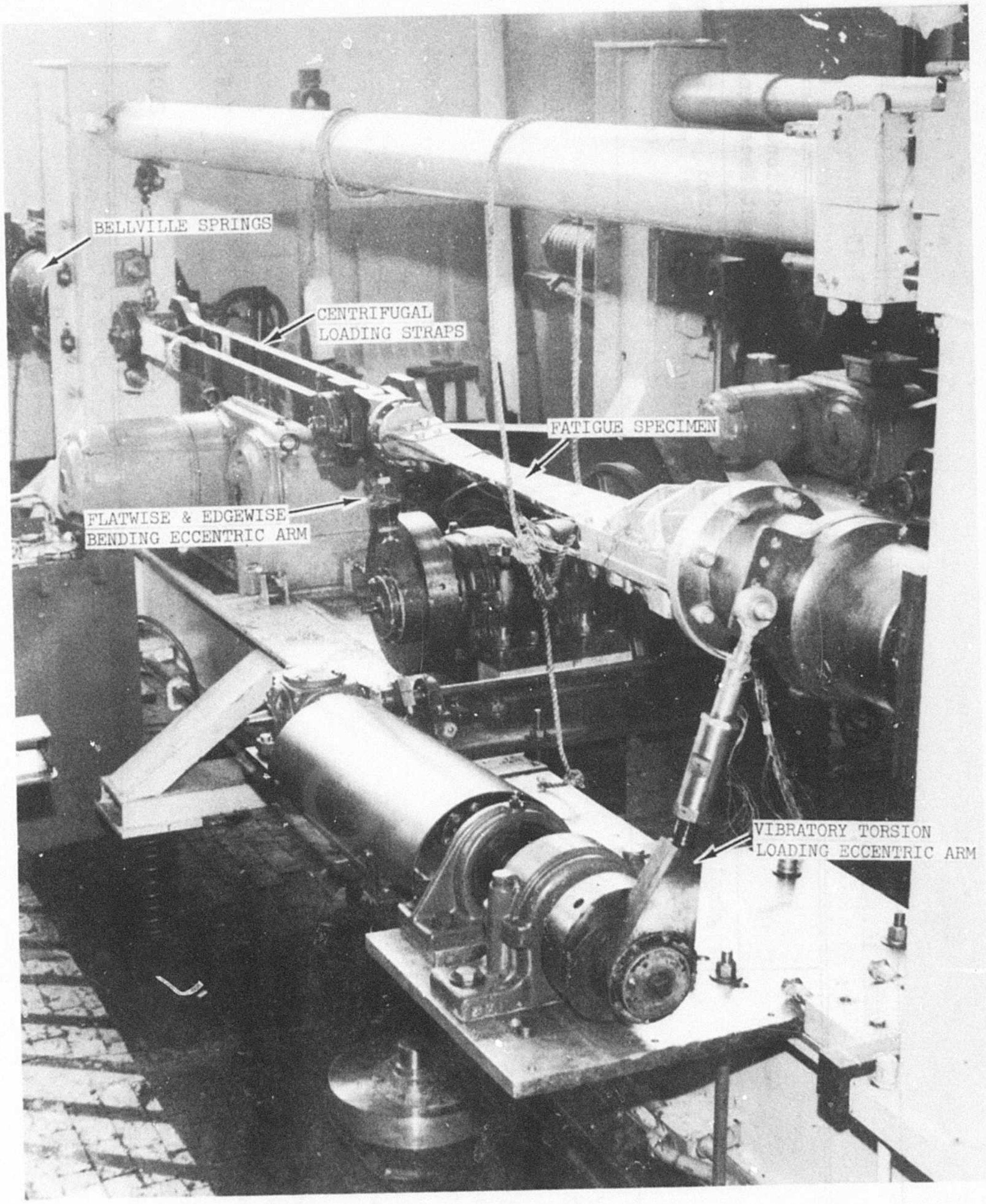


Figure 75. Fatigue Test Facility With Specimen Installed.

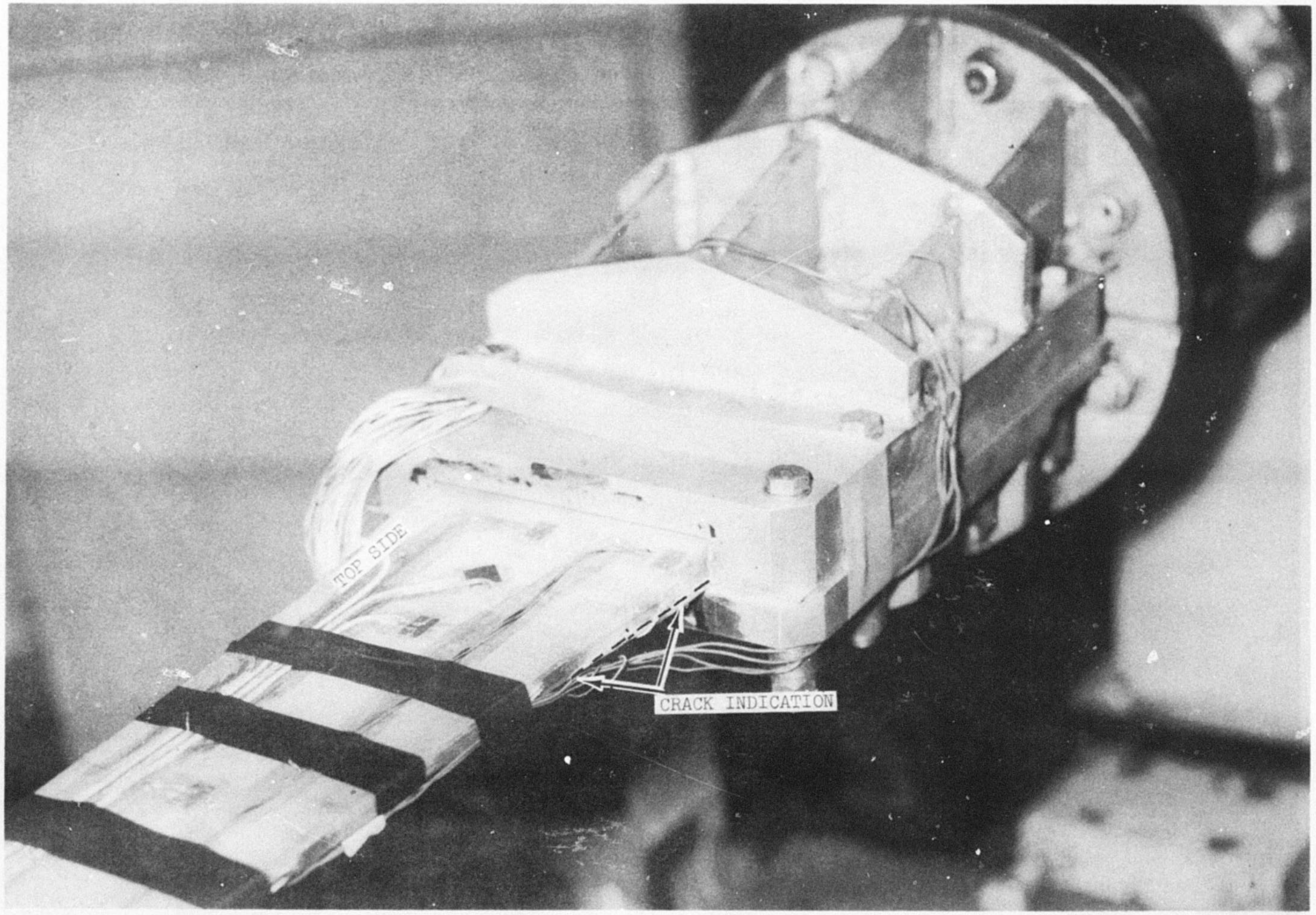


Figure 76. Fatigue Test Specimen Depicting Crack Indication.

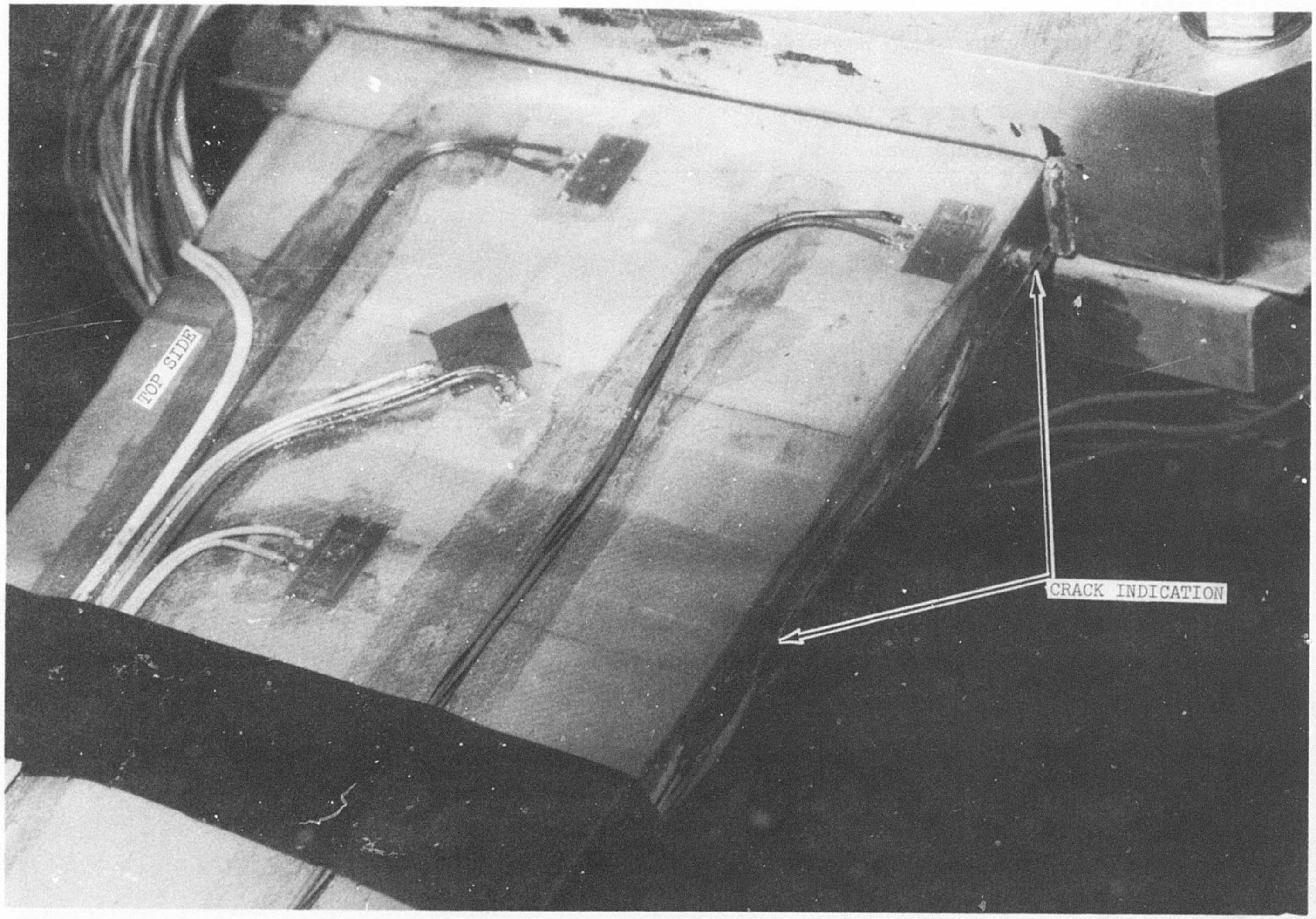


Figure 77. Closeup of Fatigue Test Specimen Depicting Crack Indication.

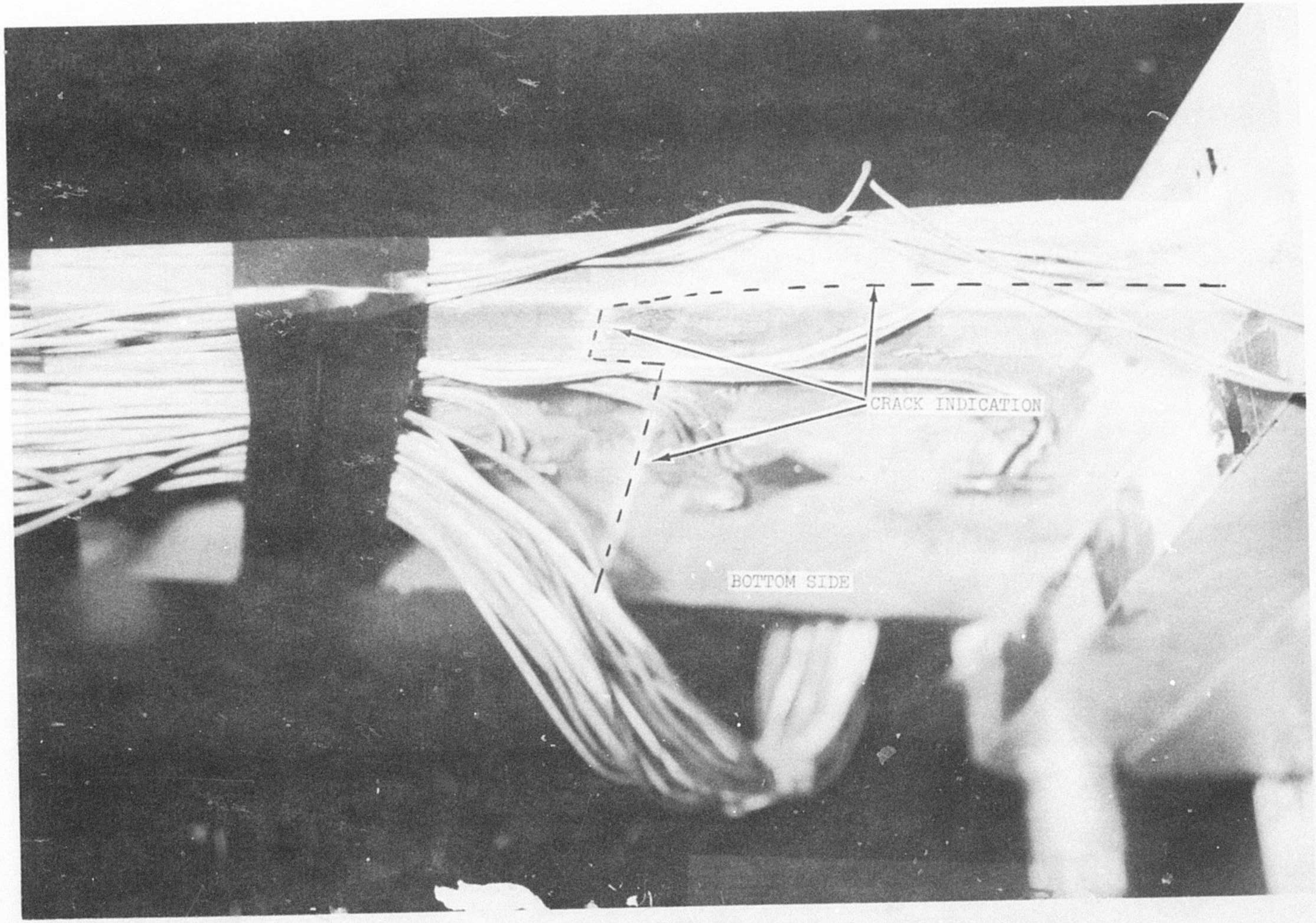


Figure 78. Fatigue Test Specimen Depicting Crack Indication Extending Onto Bottom Side.

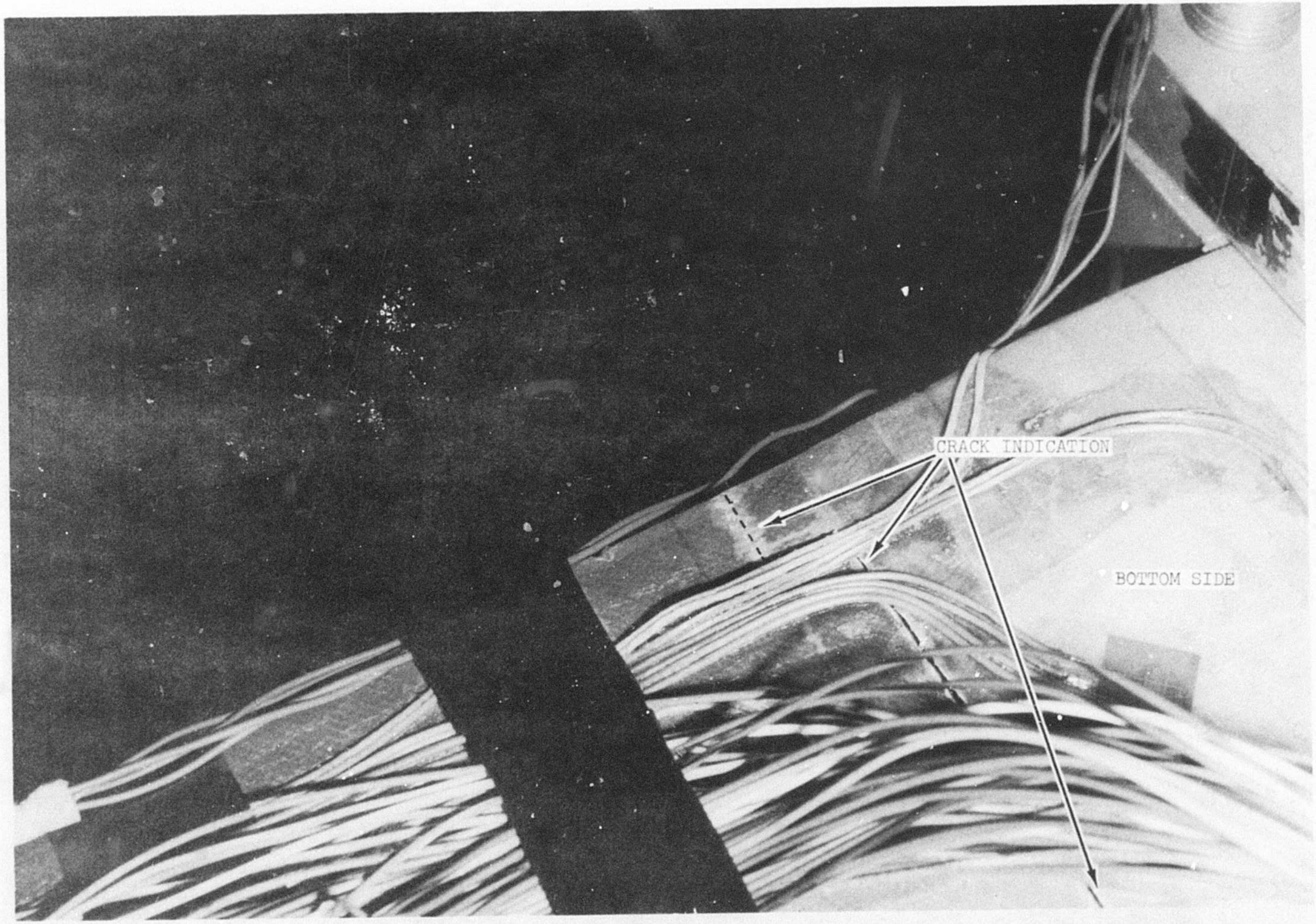


Figure 79. Closeup of Fatigue Test Specimen Depicting Crack Indication on Bottom Side.

TABLE 17. SUMMARY OF FATIGUE TEST LOADS AT STATION 7.75

Load Parameter	Orig. Predicted Design Load		Production Design, New Measured Flight Loads	Fatigue Test Condition Attained
Edgewise Moment (in.-lb)				
Steady		1000	2700	0
Vibratory		±5900	±8000	±12,530
Flatwise Moment (in.-lb)				
Steady		1200	1950	0
Vibratory		±5400	±7000	±10,150
Torsion (degrees twist)				
Steady		7	5.0	5.0
Vibratory		±4	±3.75	±7.5
Centrifugal Force		21,000	21,000	24,300
Acceleration Factor for Vibratory Loads Relative to New Flight Loads	Vib. Moment	0.7	1.0	1.5
	Vib. Torsion	1.05	1.0	2.0

Fatigue Root End Evaluation. In order to determine the cause and mechanism of fracture, stiffness measurement, visual and pulse-echo ultrasonic inspection, failure analysis, and structural analysis were performed.

Stiffness measurements of the fatigue specimen after crack detection were performed for comparison to values before the test. No significant difference in stiffness was detected. The change observed in the before and after measurements, e.g., the 3 percent in the flatwise direction, is generally within the normal scatter of measuring and is not considered a significant change. Figure 80 depicts the stiffness measurement setup. Figures 81, 82, and 83 are plots of each load direction at the maximum load used in the stiffness measurement. These plots depict the high load deflection obtained at each spar station during the calibration. These deflection conditions illustrate that there is no significant change in the before and after measurements.

Both visual and pulse-echo ultrasonic inspection of the spar root end revealed an apparent delamination in the bottom side prepreg doubler plies that extended from Station 5 to Station 10 and across the width of the specimen completely. Figure 84 illustrates the planform of the apparent delaminated area. The spar was sectioned for failure analysis and confirmation of the delamination. Sectioning confirmed that a planar interlaminar type separation had occurred between ply #9 and ply #10 of the bottom prepreg doubler plies as illustrated in Figure 85. The delamination between plies #9 and #10 is located approximately in the mid position of the nineteenth ply doubler buildup. The extent of the actual delamination was identical to that area detected by visual and ultrasonic inspection. The delamination did extend across the full width of the graphite-epoxy spar. However, the glass-epoxy outer wraps did not fracture along the leading or trailing edge and, therefore, obscured the delamination during previous visual inspection. Evidence of crazing was observed on the glass-epoxy outer wrap.

Review of the drawing requirements and the actual fracture surface confirmed that ply #9 was a 0° graphite-epoxy ply that extended to Station 10.5 and that ply #10 was a + 20° graphite-epoxy ply that extended to Station 10. The fracture surface was typical of an interlaminar shear type surface with no peculiarities or foreign substances detected. The interlaminar shear strength of the prepreg material (NARMCO AS-5209) was 14-15 ksi. This was based on actual specimens taken from the 0° material located in the torpedo in the center plug of this spar (S/N 7). This is well above the 11,000 psi minimum requirement and the 10,000 psi design allowable used for the pultruded spar design. No other abnormalities or cracks were observed in either the prepreg doublers or the pultrusion other than that described. Ultrasonic C-scan of the spar prior to testing had shown no indications at the 38dB level. This is the same sensitivity used for the static test spar and production BLACK HAWK spars.

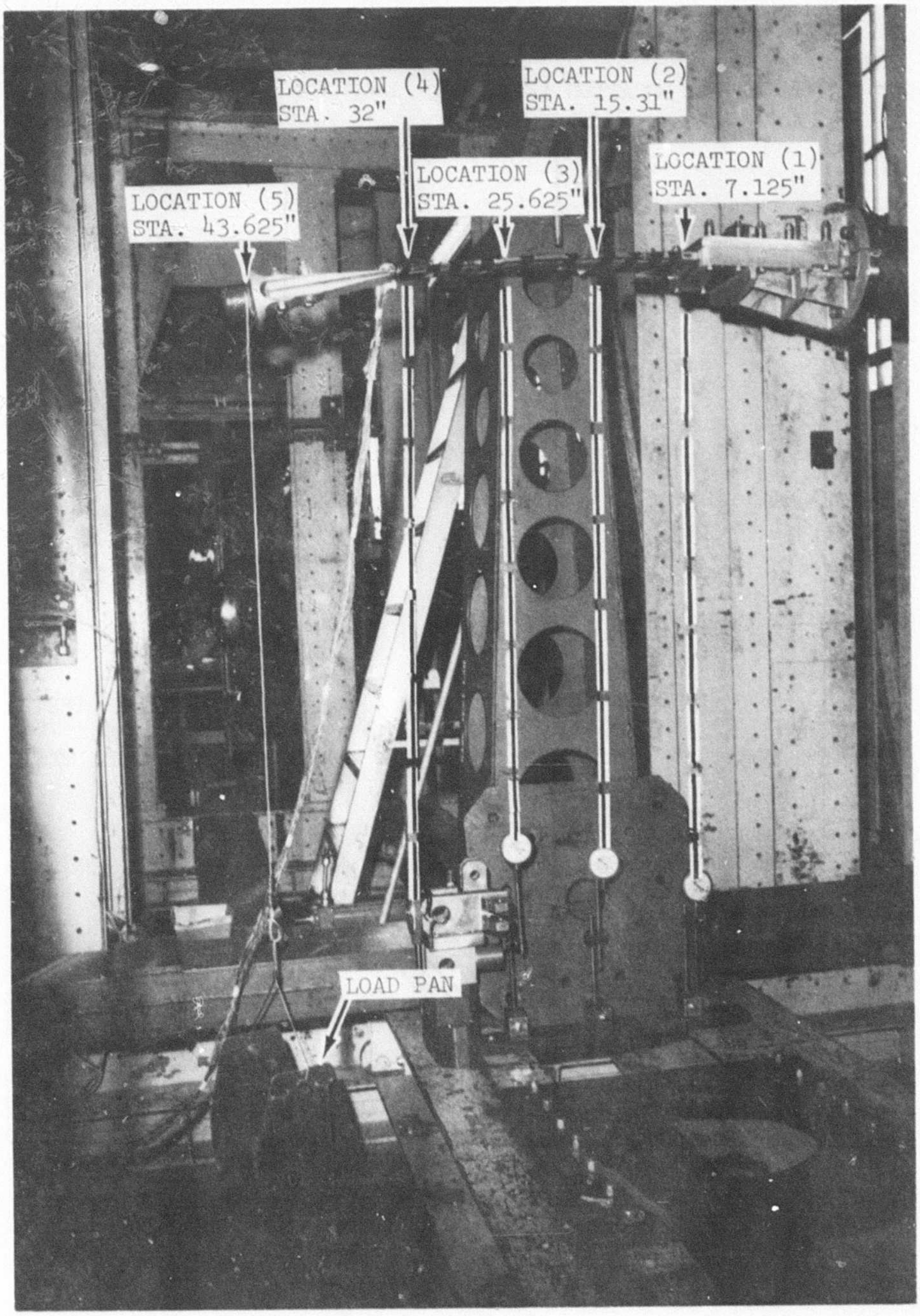


Figure 80. Load Deflection Stiffness Calibration Setup.

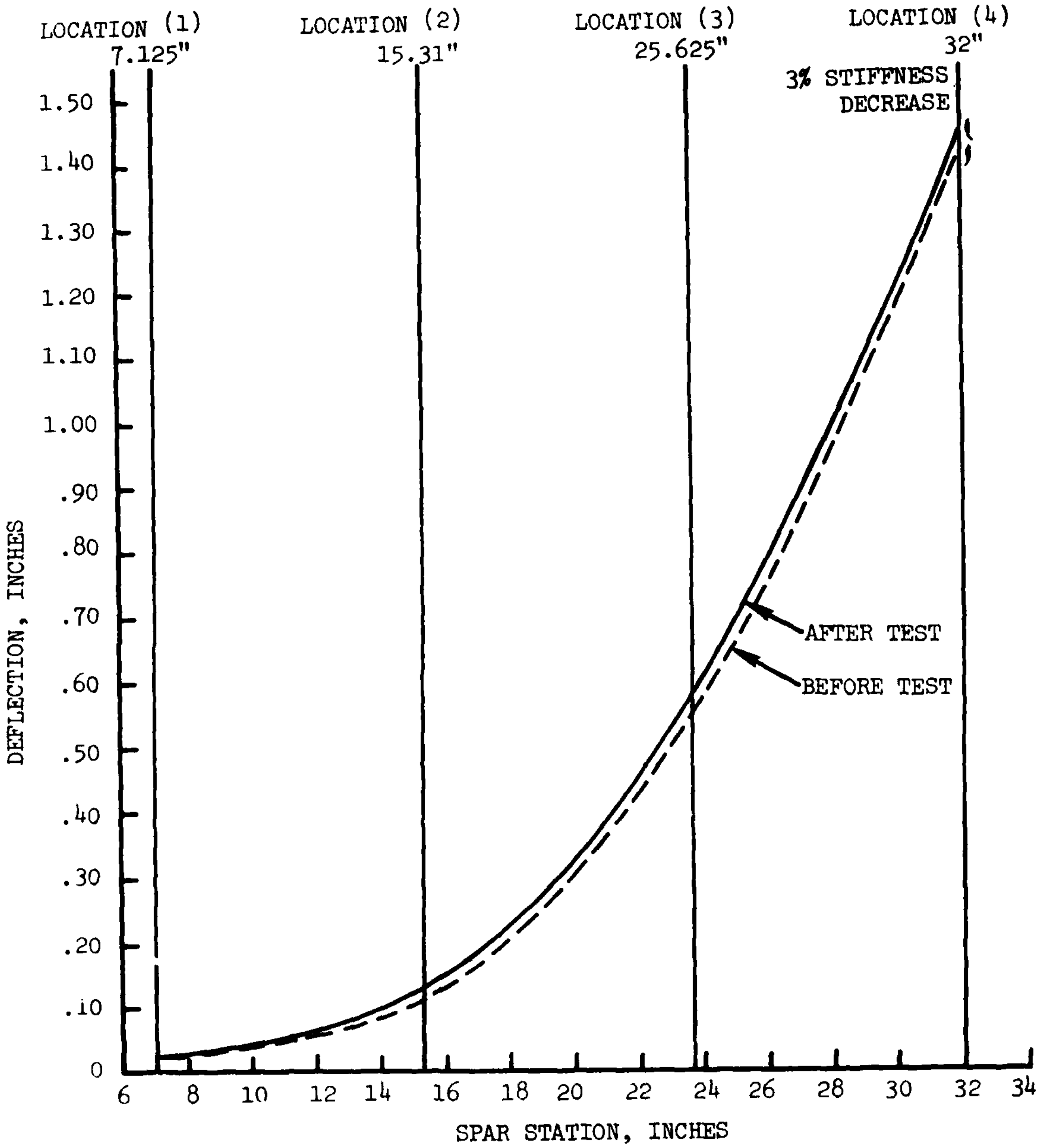


Figure 81. Flatwise Stiffness Curves of Fatigue Root End Test Specimen Before and After Testing.

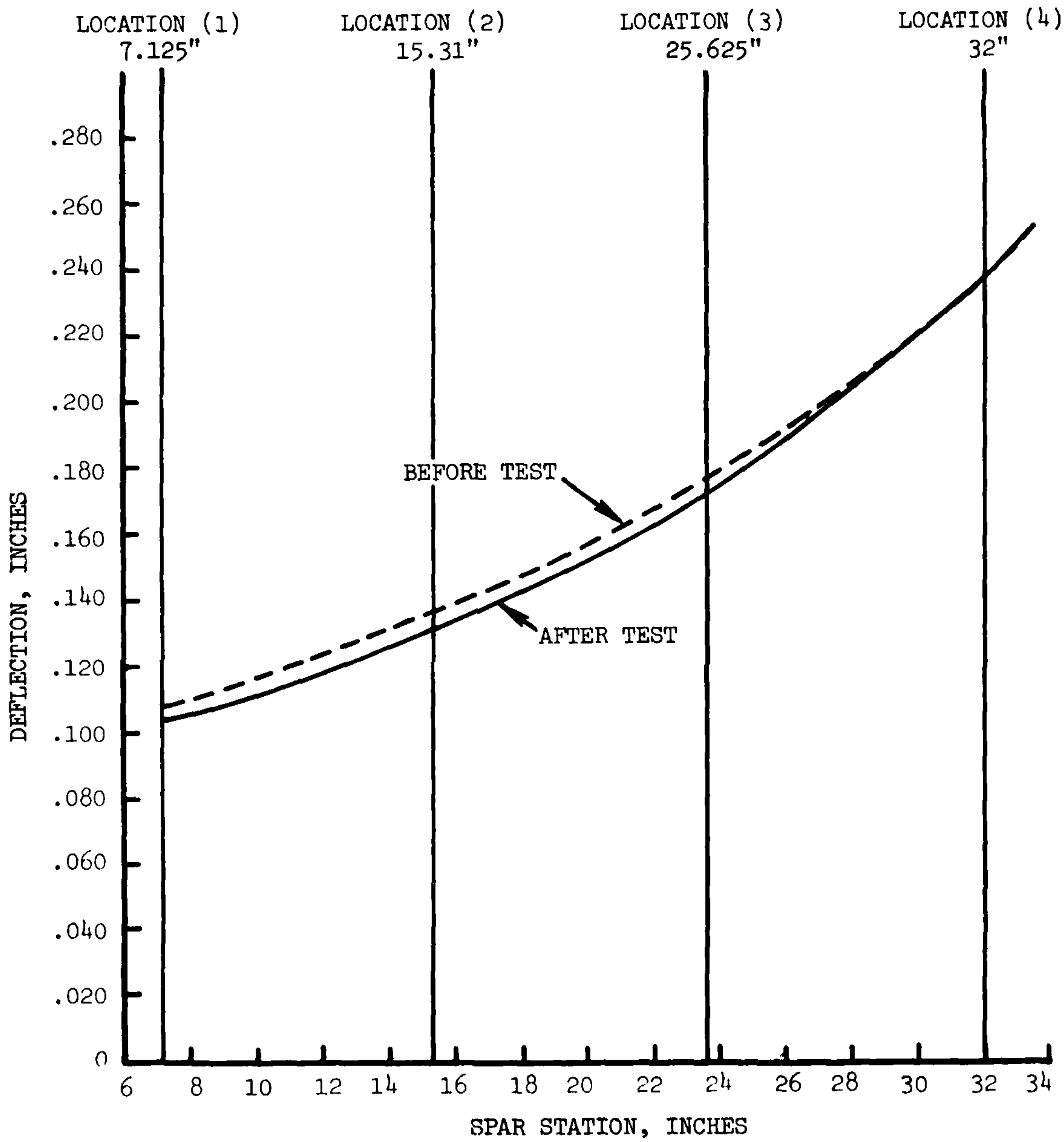


Figure 82. Edgewise Stiffness Curves of Fatigue Root End Test Specimen Before and After Testing.

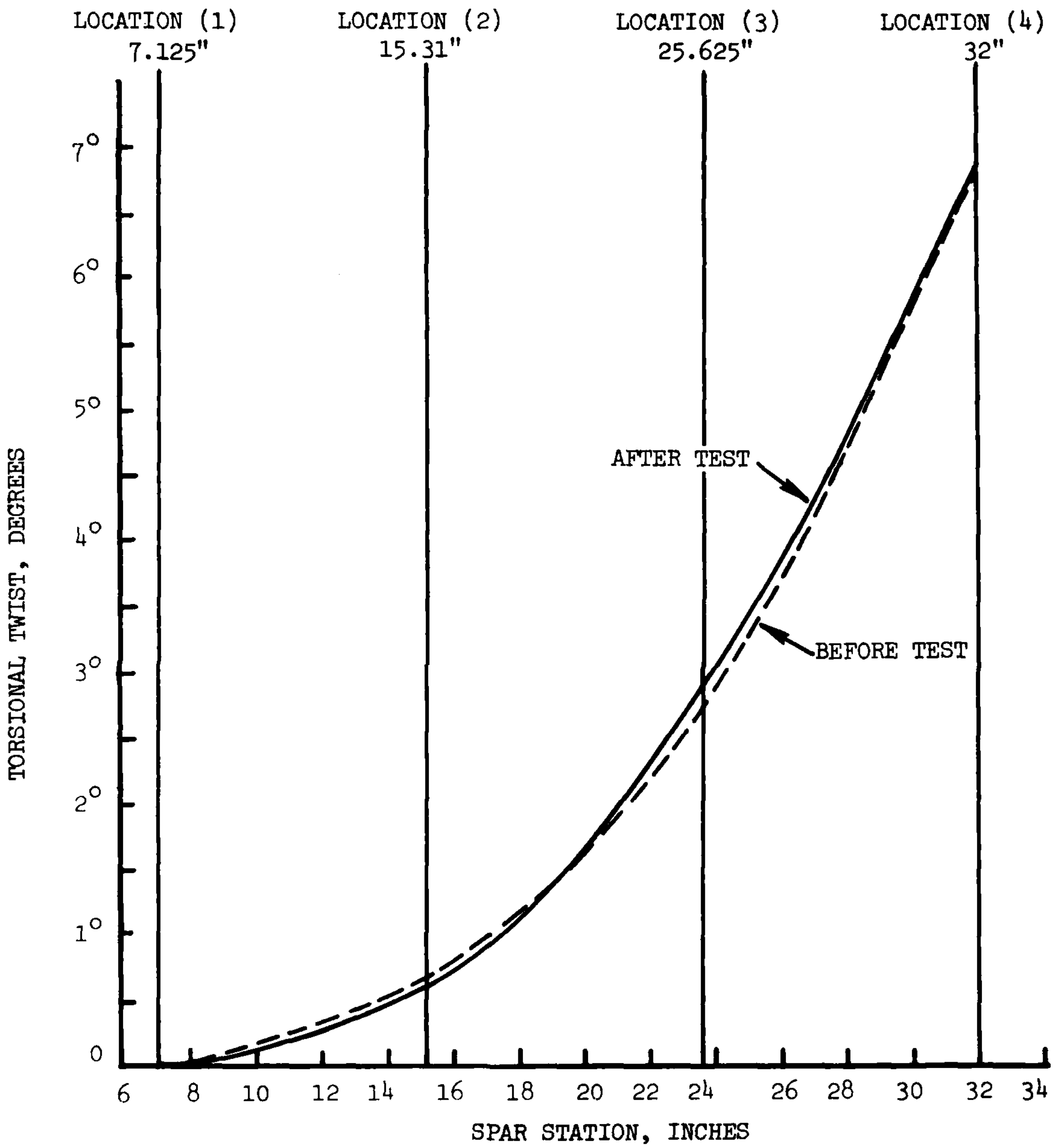


Figure 83. Torsional Twist Stiffness Curves of Fatigue Root End Test Specimen Before and After Testing.

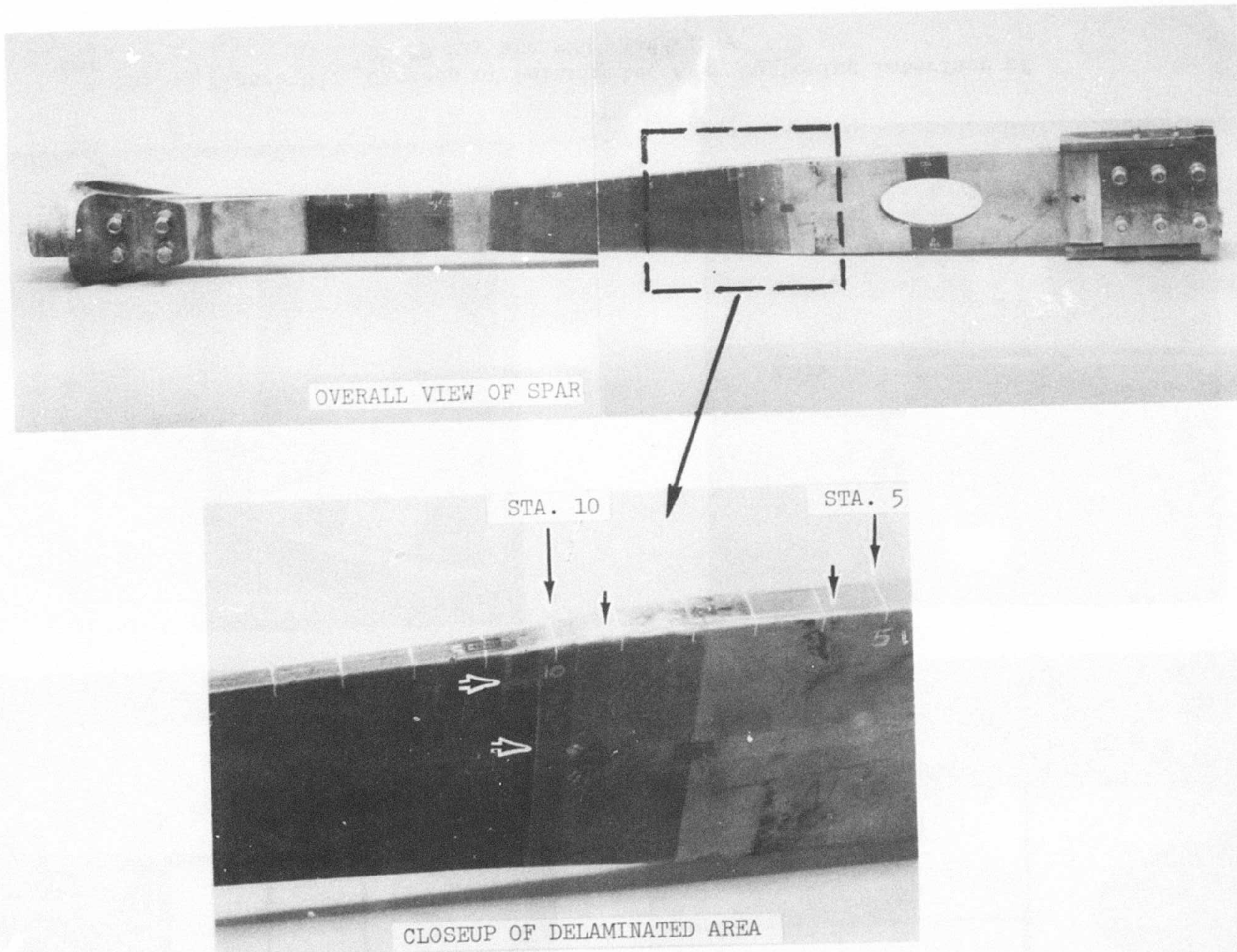


Figure 84. Fatigue Crack Indication in Root End Fatigue Test Specimen, S/N 7.

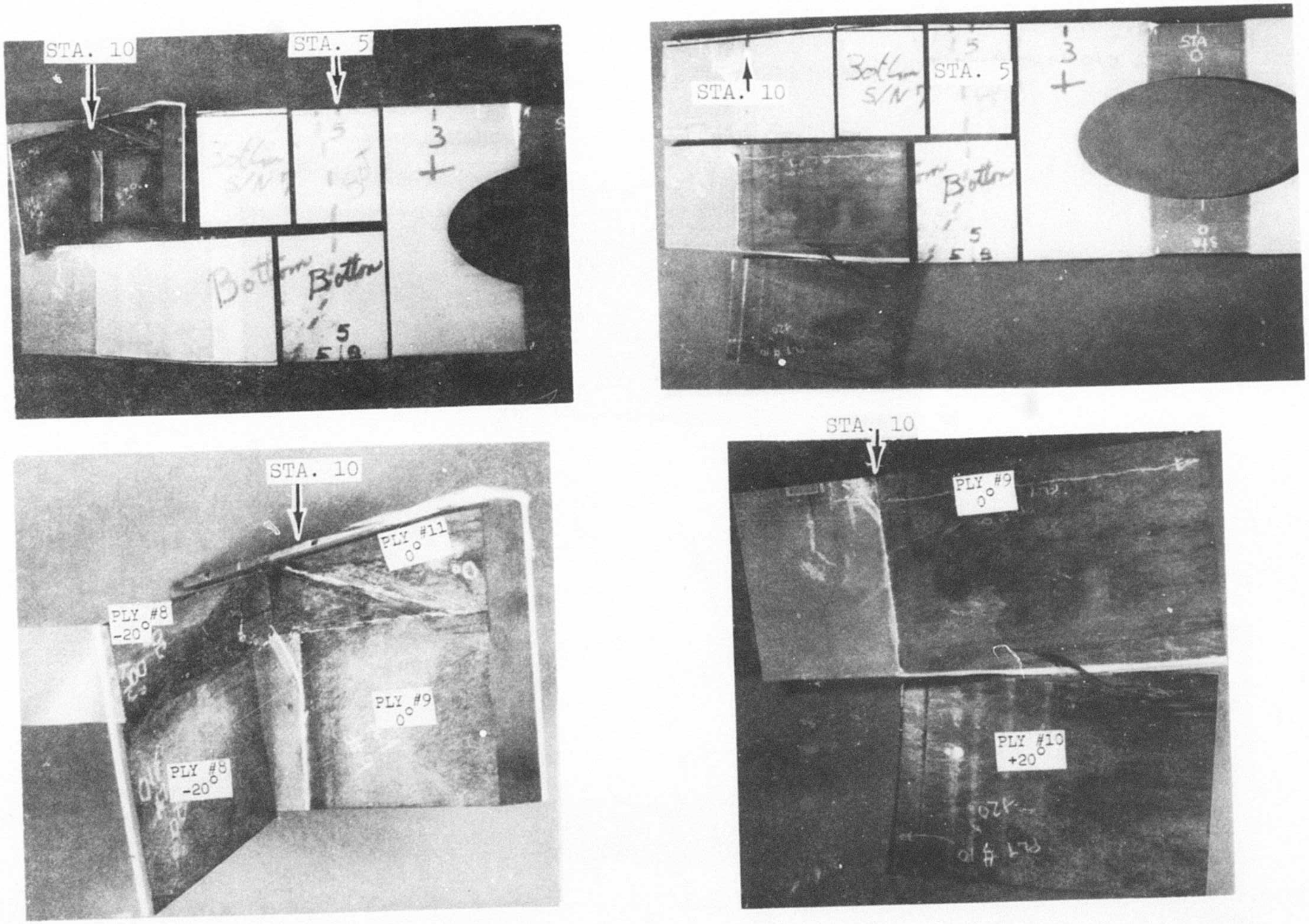


Figure 85. Closeup of Delaminated Area Depicting Interface of 0° #9 Ply and +20° #10 Ply.

Structural analysis of the root end fatigue test specimen, S/N 7, revealed that the interlaminar shear failure occurring at Station 10 was predictable analytically, based on small specimen data and on the test loading conditions. The data also disclosed that the existing pultruded spar root end design was inadequate for production BLACK HAWK aircraft when the higher production load requirements were in the analysis. Based on the structural analysis, a new pultruded spar root end design concept that provided a positive structural margin was formulated. The new pultruded spar root end design entailed the use of a center insert of 0° and $\pm 20^\circ$ graphite prepreg material, top and bottom torpedoes of 0° graphite prepreg material, a four-piece pultrusion of 0° graphite material, and a top and bottom outer cover two-ply skin of 0° graphite prepreg material. Figure 86 depicts the new pultruded spar root end design concept.

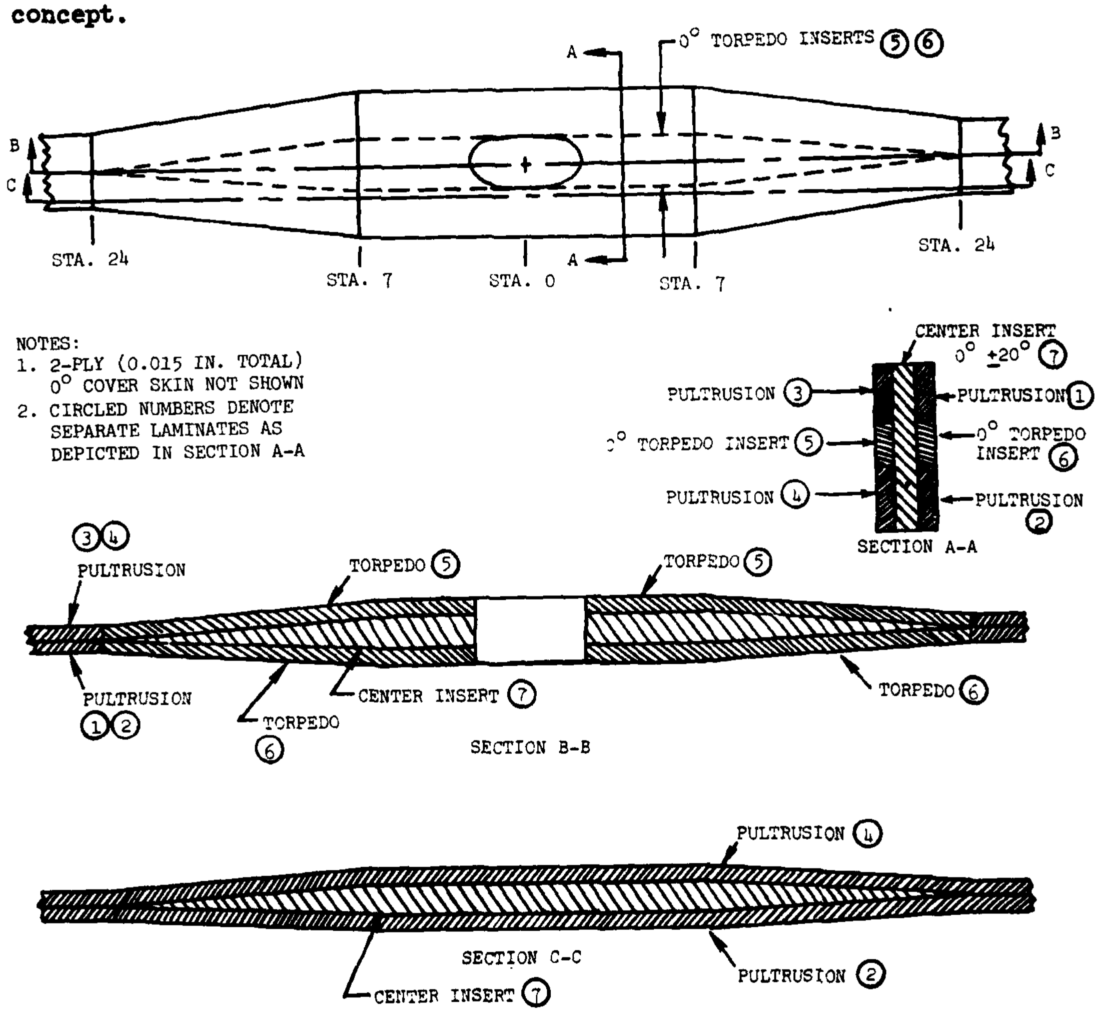


Figure 86. Recommended Production Root End Pultrusion Design. (With center insert, four-piece pultrusion, top and bottom torpedoes, and top and bottom outer cover skin).

PHASE V - FINAL DESIGN MANUFACTURING METHODS ASSESSMENTS

As a result of the design modification that changed the torque rib design on the production BLACK HAWK spar assembly, portions of the full-scale static and fatigue specimen testing and evaluation phase were deleted from the current program's scope of work. A final design manufacturing method assessment phase was then incorporated into the program's scope of work. This new effort involved redesigning the pultrusion root end, incorporating all the design changes in the production UH-60A BLACK HAWK tail rotor assembly, inputting the data obtained from the previous phases into the design, fabrication and static testing of a pultruded torque rib spar specimen, and fatigue testing of a pultruded outboard tail rotor blade specimen. As the design of the pultruded torque rib and redesign of the root end was evolving, the production prepreg BLACK HAWK design was undergoing fatigue testing. Feedback from the fatigue tests resulted in design modification to the production prepreg BLACK HAWK spar and was simultaneously reflected in the design of the pultruded spar. The design modification necessitated a hold on the pultruded design and caused a slippage in the program schedule. This slippage resulted in the customer partially terminating the program. Prior to termination, redesign of the root end and proposed design of the pultruded design torque rib were achieved.

Design of Outboard Torque Rib/Spar

Approximately midway along the production BLACK HAWK tail rotor blade radius, a structural joint exists between the outboard spar-honeycomb-skin structure and the inboard spar-torque tube structure. This joint serves to distribute the bending, torsional and centrifugal loads from the outboard structure to the inboard structure. In order to accomplish this load transfer, the torque tube skin and spar become effectively a single solid bond composite structure at the joint area. The original YUH-60A UTTAS joint design used an external buildup torque rib of bonded fiberglass epoxy as illustrated in Figure 87A. Due to increase in design loads at the torque rib transfer area, redesign of the joint design was required. The increased loads were detected during UH-60A BLACK HAWK fatigue substantiation testing. Redesign for the production UH-60A production BLACK HAWK aircraft involved elimination of the fiberglass ribs and buildup of the spar with graphite-epoxy prepreg locally disbursed throughout the 0° plies. In addition, three bolts through the thickness dimension of the spar serve as clamping fasteners to prevent delamination due to any interlaminar prying stress that exists in the joint. A sketch of the joint area for the production BLACK HAWK tail rotor spar is provided in Figure 87B.

Design efforts were directed toward establishing an acceptable joint at this location for the pultruded spar configuration. The buildup of the spar is obtained by alternately interleaving 0° and $\pm 45^\circ$ plies of graphite material until the required thickness is obtained. The intent in the design of the pultruded spar joint is to have it similar to the production blade joint geometrically in order that the pultruded spar can interface with all other existing rotor components. The production joint cannot be structurally duplicated because ply-by-ply interleaving of the lamination

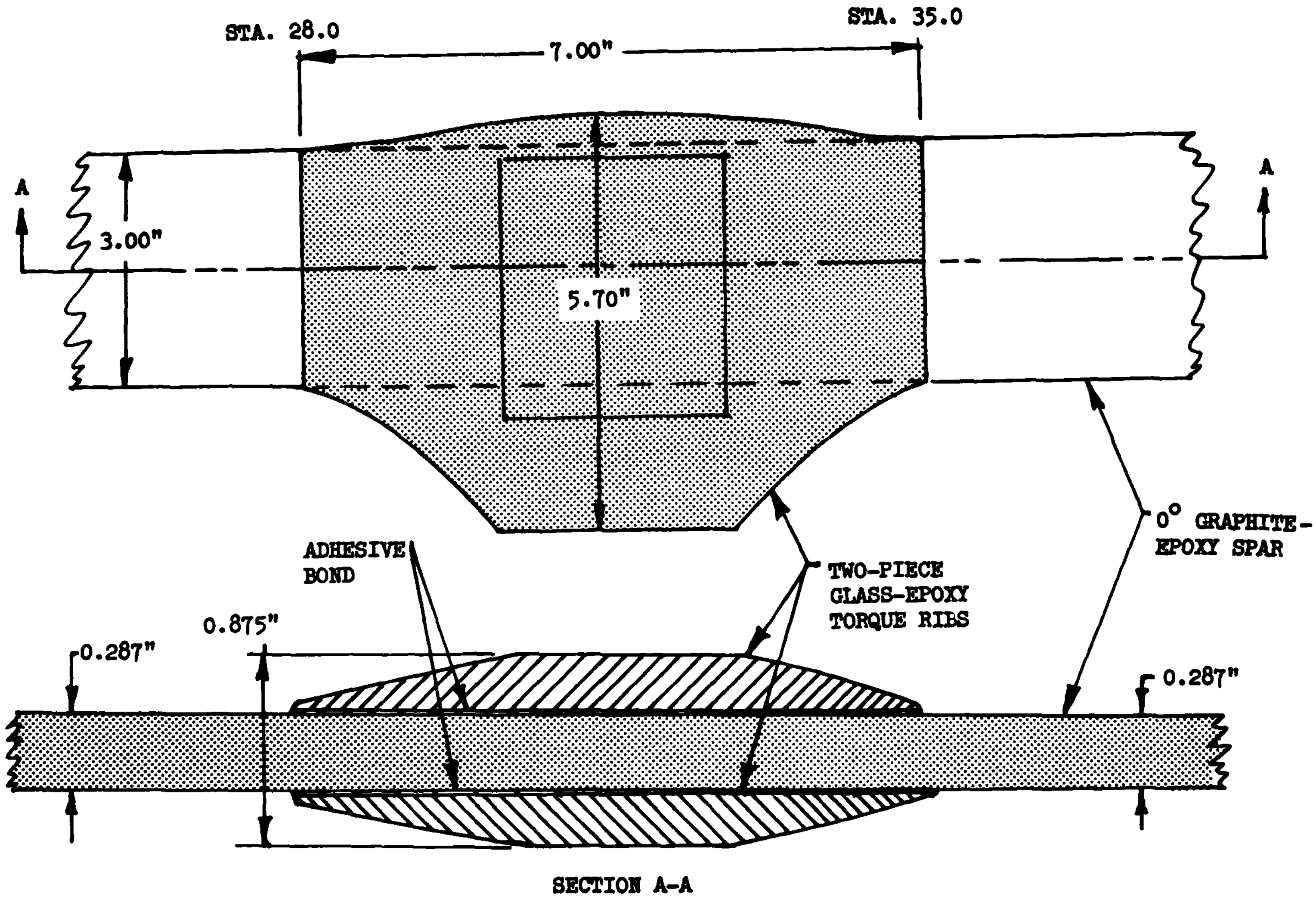


Figure 87A. Original YUH-60A UTTAS Torque Rib Configuration.

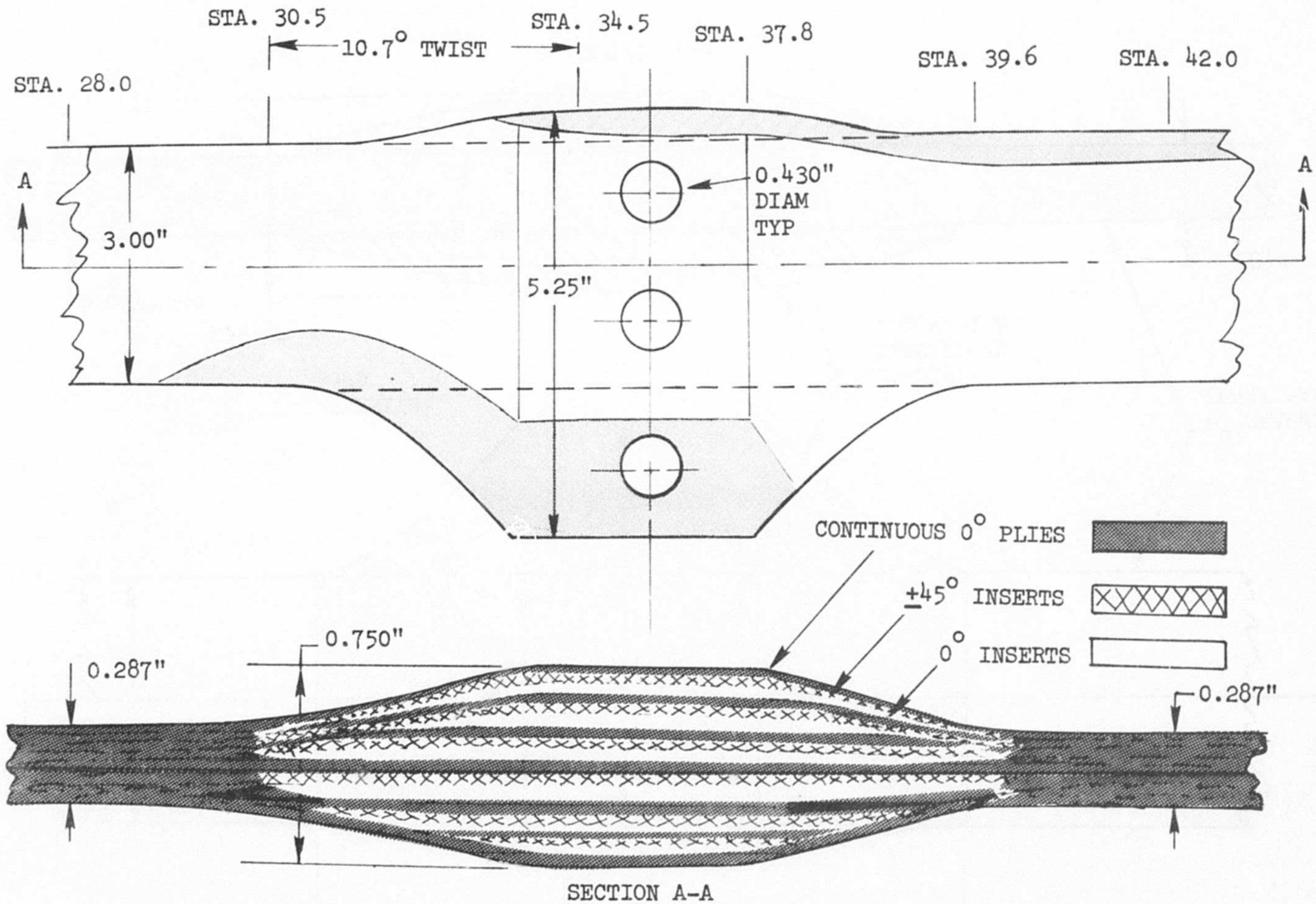


Figure 87B. New Production UH-60A BLACK HAWK Torque Rib Configuration.

is not practical with a pultrusion. Other approaches had to be employed in order that the pultrusion width and thickness would be similar to the production dimensions.

Several practical approaches were developed and are illustrated in Figures 88 through 95. The simplest design to fabricate is shown in Figure 88. This approach involves butting unidirectional prepreg inserts against each side of the uncured pultrusion to form the required width dimension. Top and bottom tapered plates of uncured cross ply and unidirectional prepreg are laid over the joint to form the thickness buildup. This assembly is then cocured and machined to the final edge geometry similar to BLACK HAWK production design. The structural risks involved in this design are primarily due to the shearing stresses that are associated with transferring the load from the pultrusion to the side members. Figure 96 shows a finite element model that was used to assess the critical load transfer in the planform plane. The finite element model was used in conjunction with a laminate analysis to determine the critical bond joint stress. The laminate analysis was also used to calculate the interlaminar stresses between the spar and the top plates. The analysis has shown acceptable stress levels at the bolt holes and at most of the critical transition points. Analysis of this simplest concept showed it to be satisfactory.

The second concept was chosen based on improving the judged structural risks of the first concept. Concept II, shown in Figure 89, incorporates a torpedo insert through the pultrusion thickness. This design increases the pultrusion width with continuous fibers in an attempt to improve the transfer of load in the planform plane and is similar to that accomplished in the spar root end. Concept III, Figure 90, incorporates a torpedo insert across the width of the specimen to provide more fiber continuity to transfer load through the thickness buildup. Use of Concept III entails going to a four-piece pultrusion instead of the two pieces currently used for the existing root end design. Concept IV, as shown in Figure 94, is a combination of Concepts II (Figure 89) and III (Figure 90). In Concept IV torpedo inserts are used in both the thickness and width planes. Concept IV A (Figure 95) is a slight variation of Concept IV with one less piece. Each successive basic concept is more complex to fabricate, but will undoubtedly reduce structural risk. A trade-off study and analysis was performed to select two design concepts for test evaluation.

Results of the trade-off study indicated two probable torque rib design concepts with positive structural margins throughout the spar. These two concepts are Concept I (Figure 88) and Concept III (Figure 90). The first and simplest design (Concept I) for the torque rib entails a center 0° pultruded graphite material with right and left side inserts of 0° graphite prepreg material and top and bottom layers of $\pm 45^\circ$ graphite prepreg material with a top and bottom outer cover skin of 0° graphite prepreg material. A sketch of Concept I is provided in Figure 97. The second design (Concept III) for the torque rib involves a center insert of $\pm 45^\circ$ graphite prepreg material top and bottom, a right and left pultrusion of 0° graphite material with side inserts of 0° graphite prepreg material, a top and bottom layer of $\pm 45^\circ$ graphite prepreg material, and a top and

bottom outer cover two-ply skin of 0^{o} graphite prepreg material. A sketch of Concept III is provided in Figure 98. Both Concept I and Concept III of the outboard torque rib are compatible with the required four-piece pultrusion redesign of the root end.

Actual drawings of the full-scale production BLACK HAWK pultruded spar with a redesigned pultruded root end and pultruded torque rib design were generated and are presented in Figure 99.

Two separate types of static tests of the spar in the area of the torque rib/spar joint were being considered on each of the two selected designs prior to termination of the contract. One specimen of each design was scheduled for testing in flatwise bending; the second specimen was scheduled for testing in axial tension. Both tests were to be conducted to fracture.

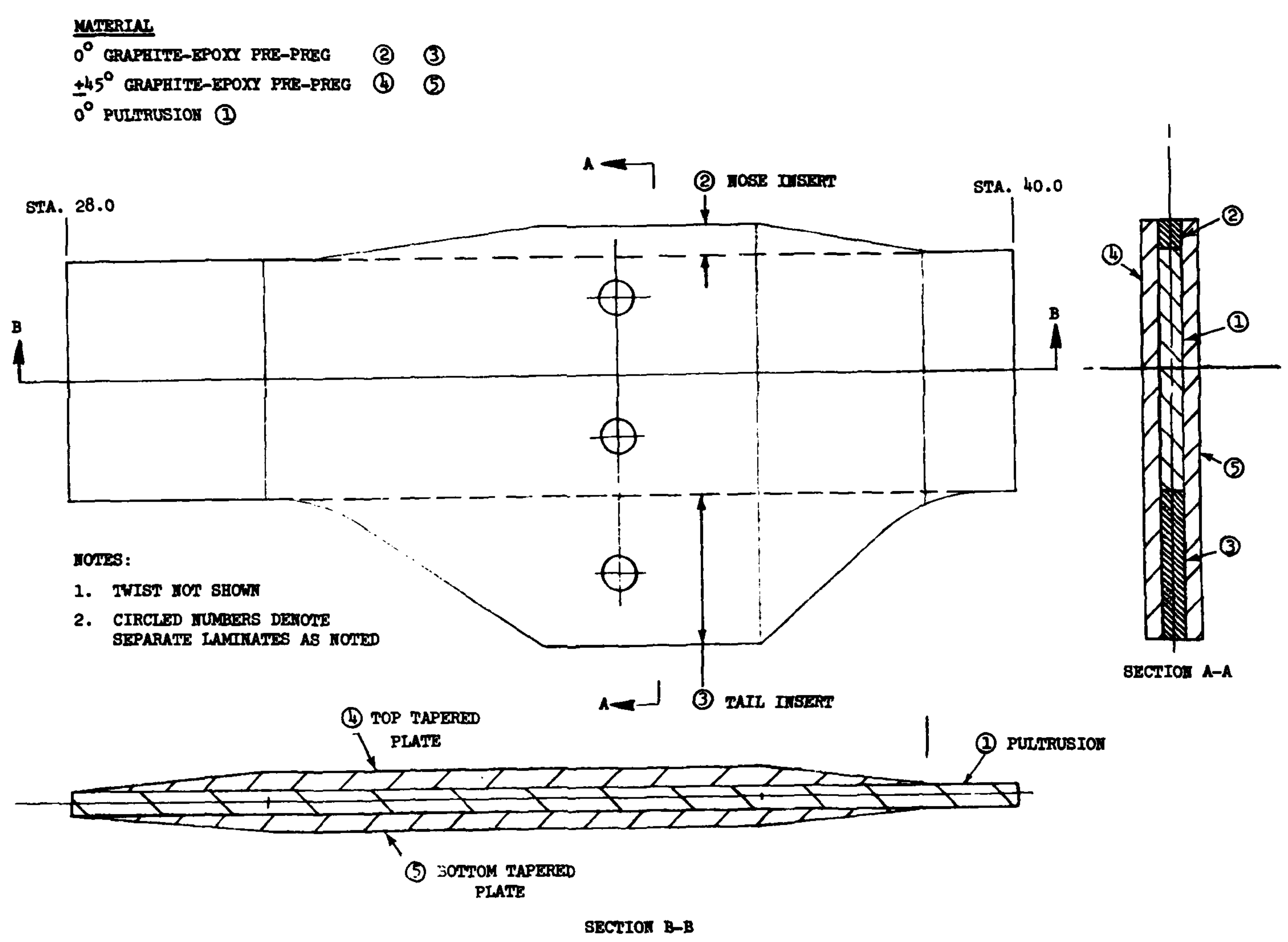


Figure 88. Pultruded Spar Torque Rib Buildup - Concept I.

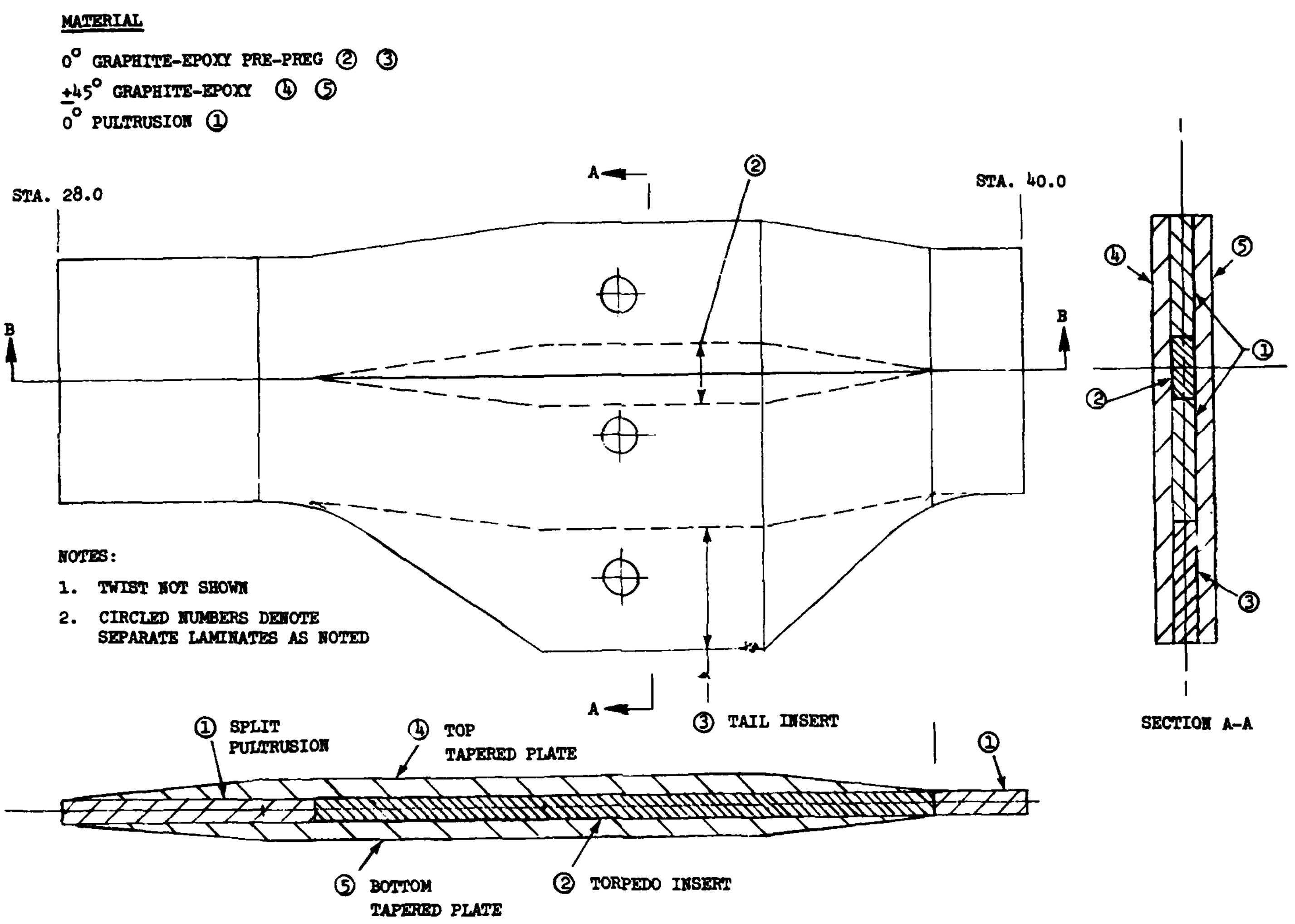


Figure 89. Pultruded Spar Torque Rib Buildup - Concept II.

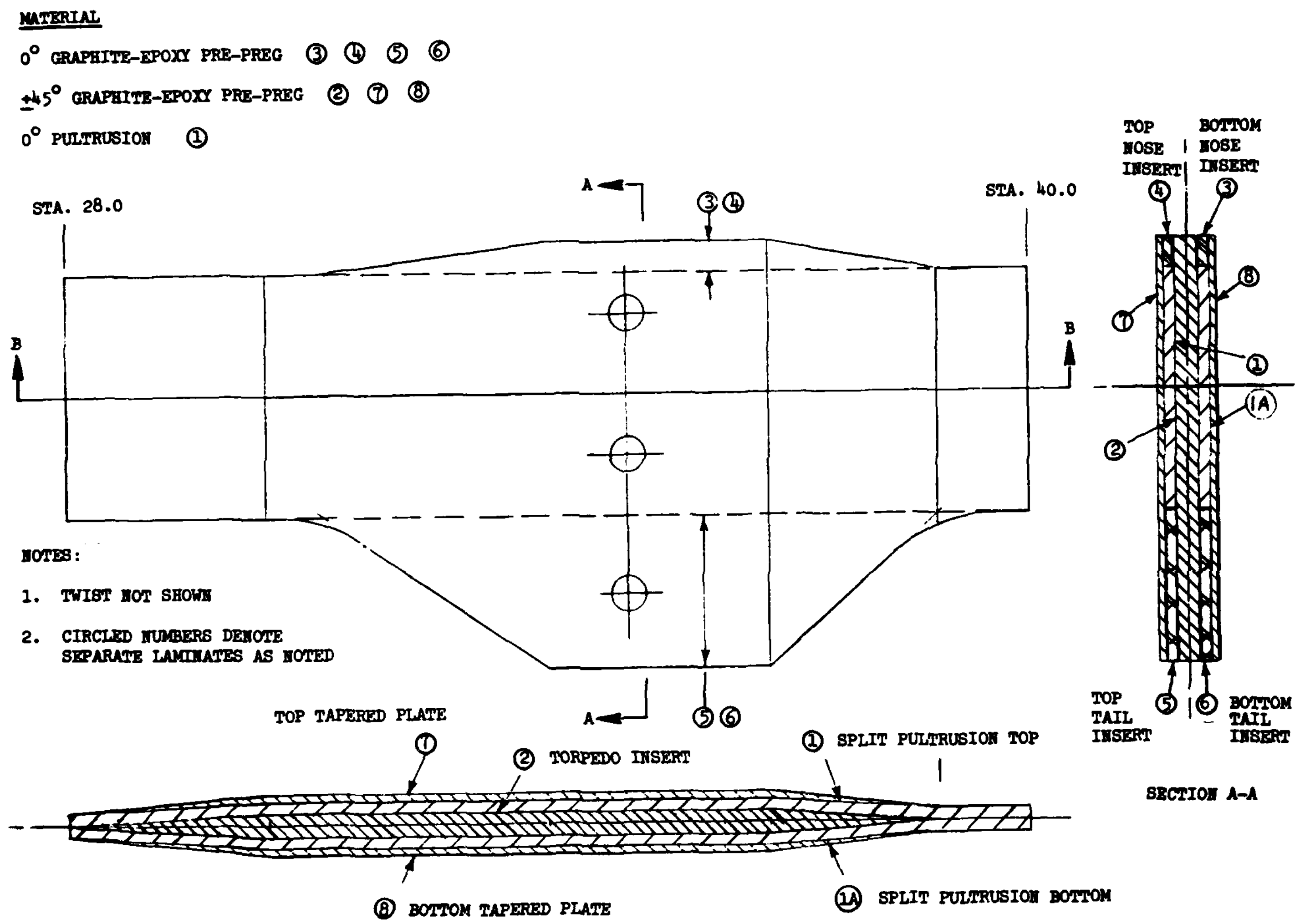


Figure 90. Pultruded Spar Torque Rib Buildup - Concept III.

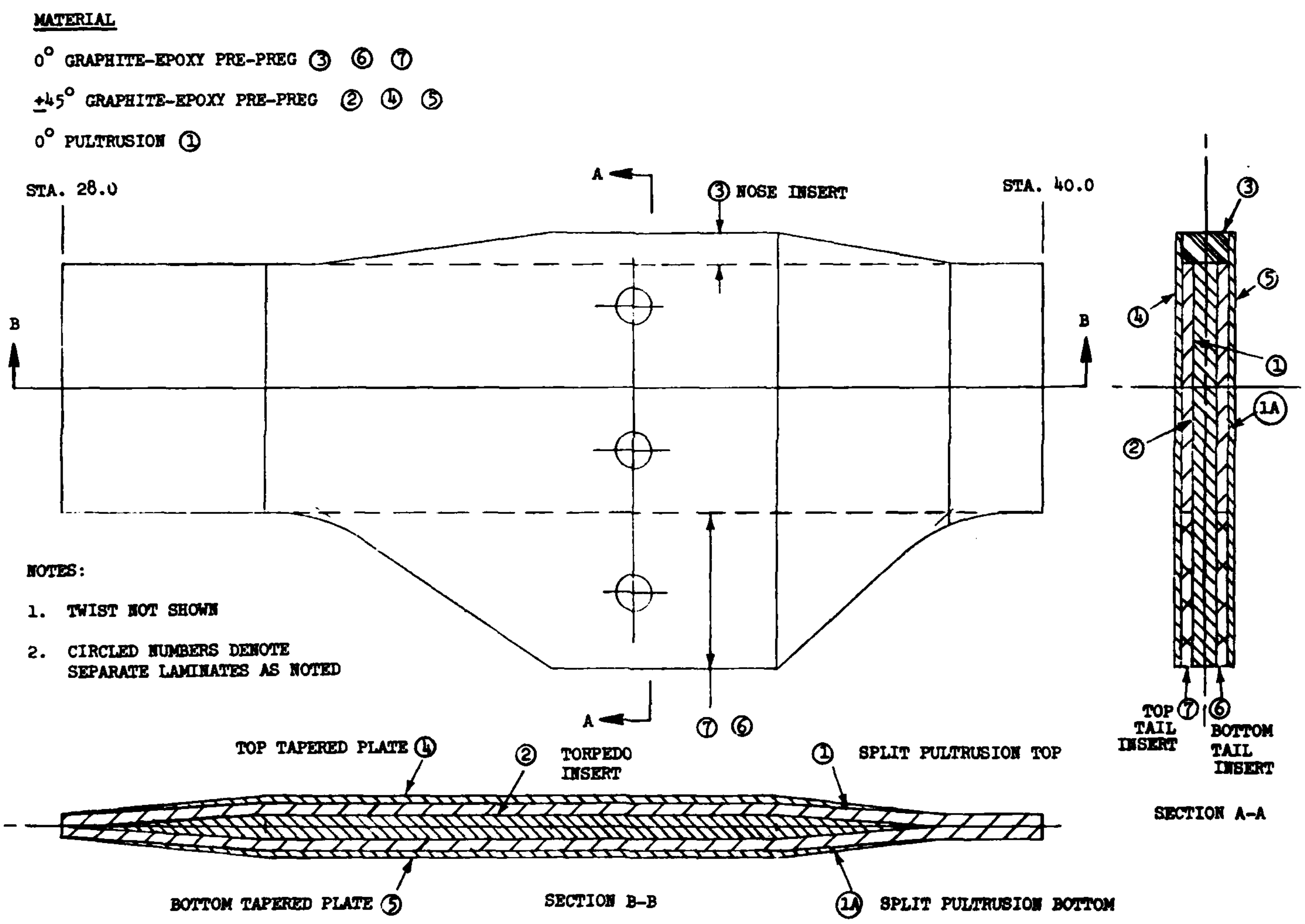


Figure 91. Pultruded Spar Torque Rib Buildup - Concept III-A.

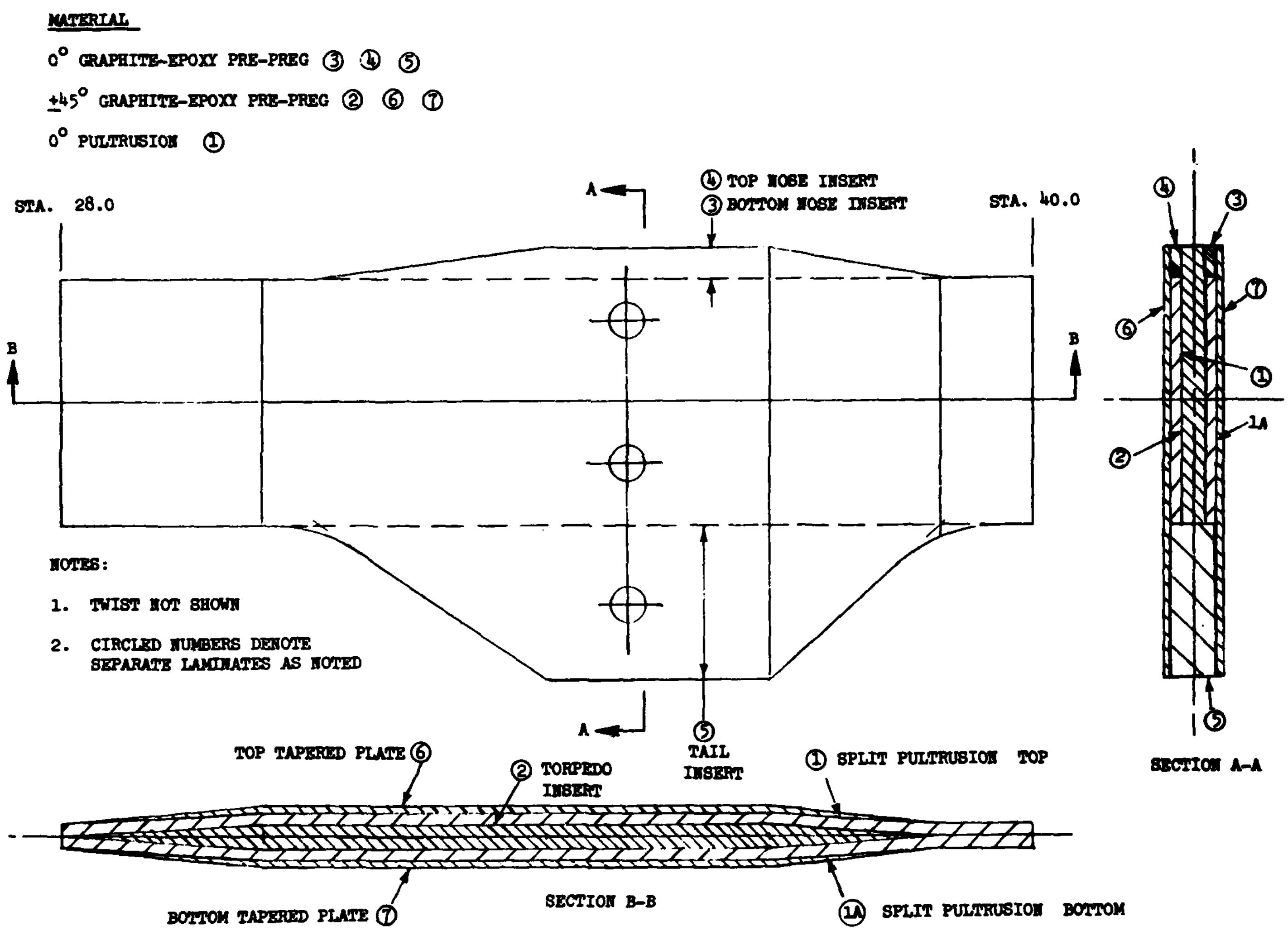


Figure 92. Pultruded Spar Torque Rib Buildup - Concept III-B.

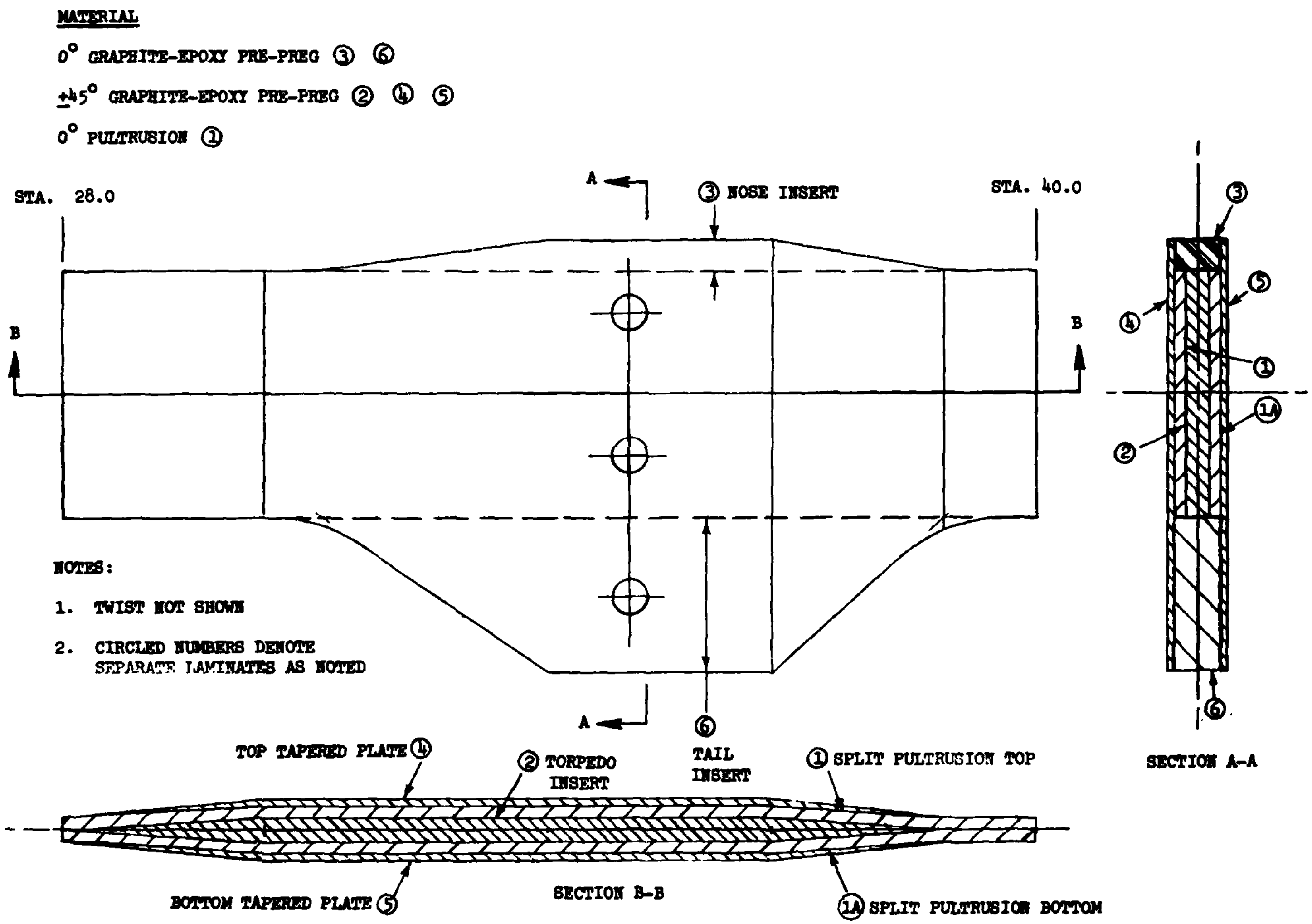


Figure 93. Pultruded Spar Torque Rib Buildup - Concept III-C.

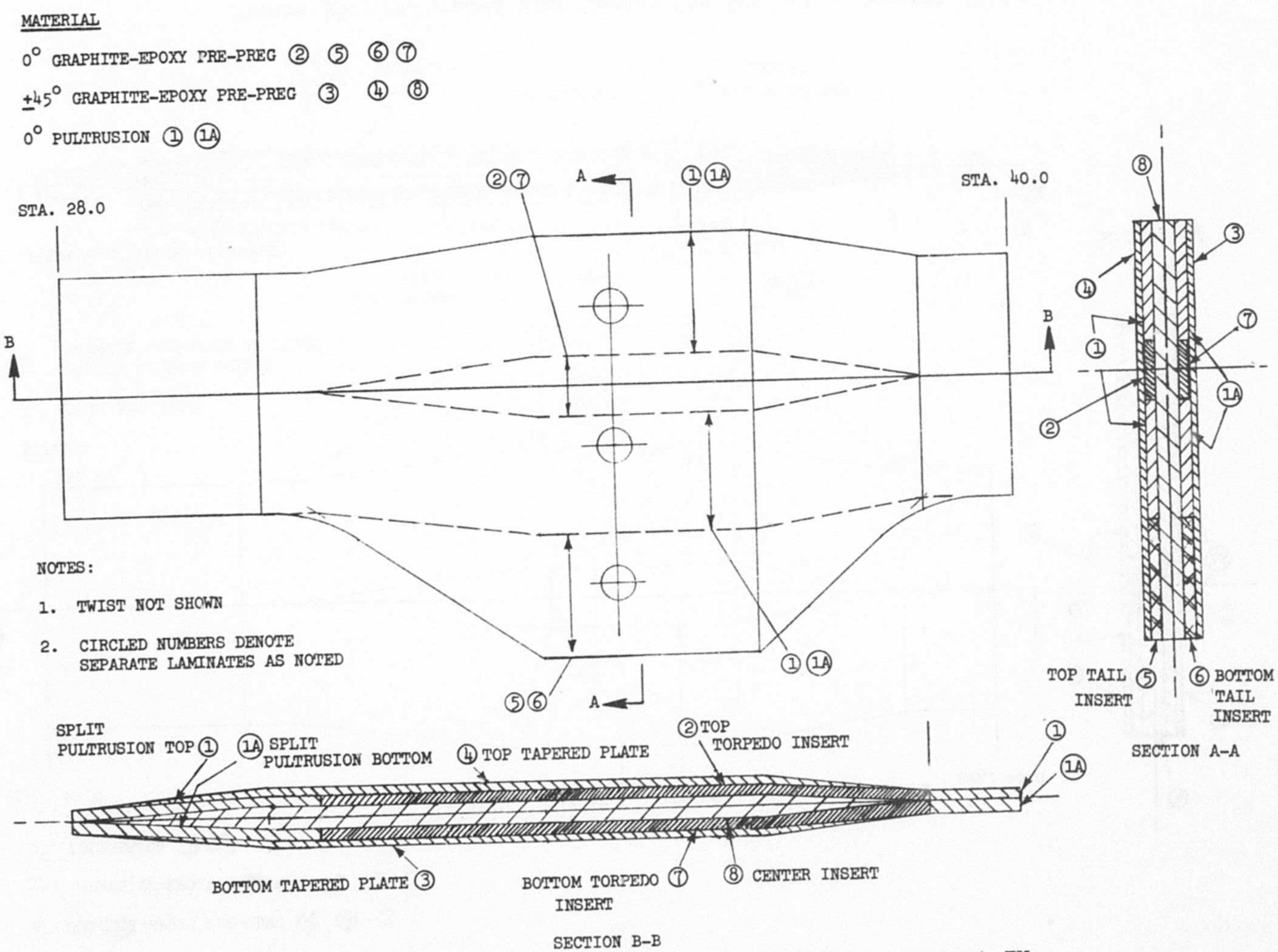


Figure 94. Pultruded Spar Torque Rib Buildup - Concept IV.

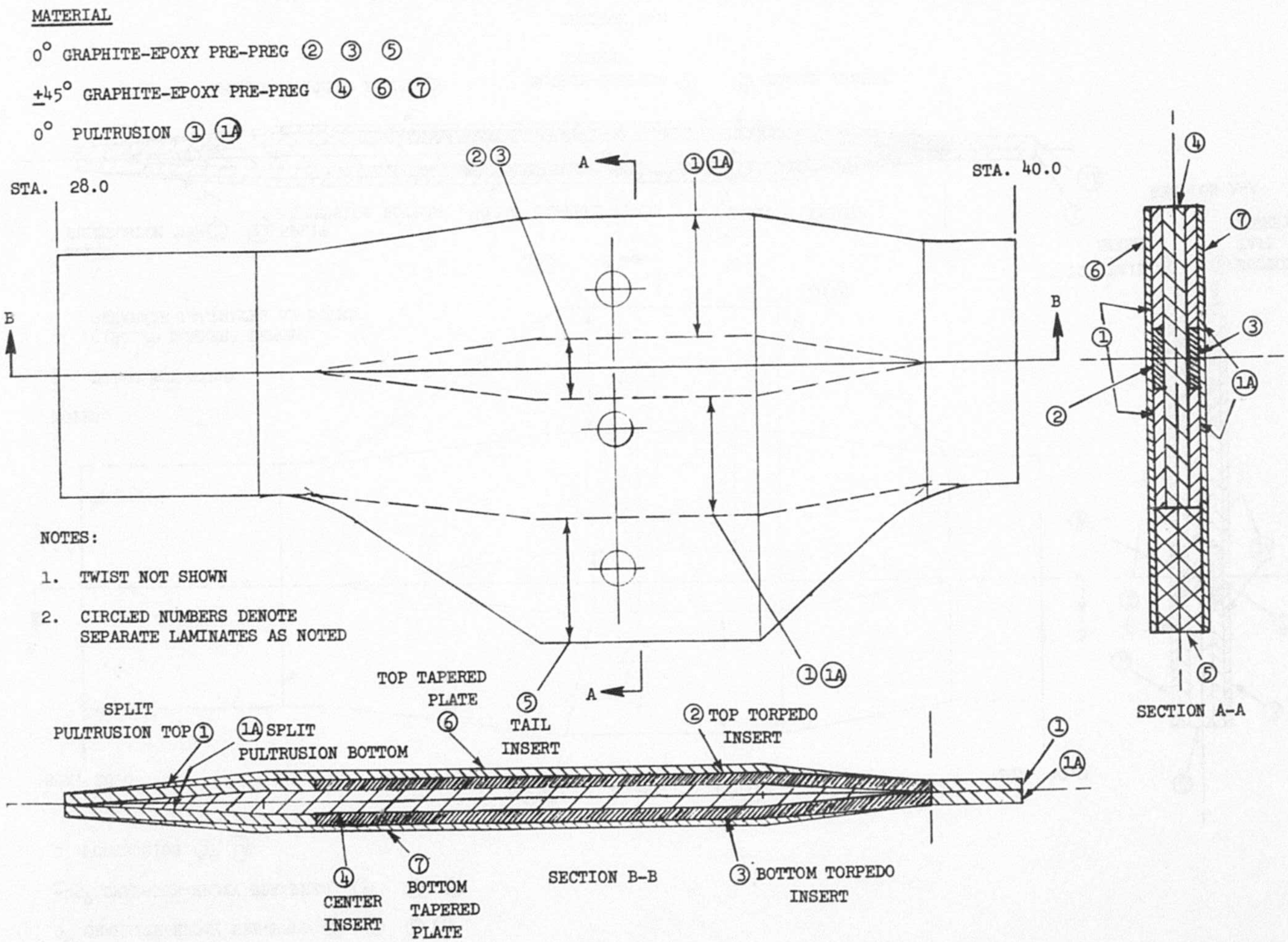


Figure 95. Pultruded Spar Torque Rib Buildup - Concept IV-A.

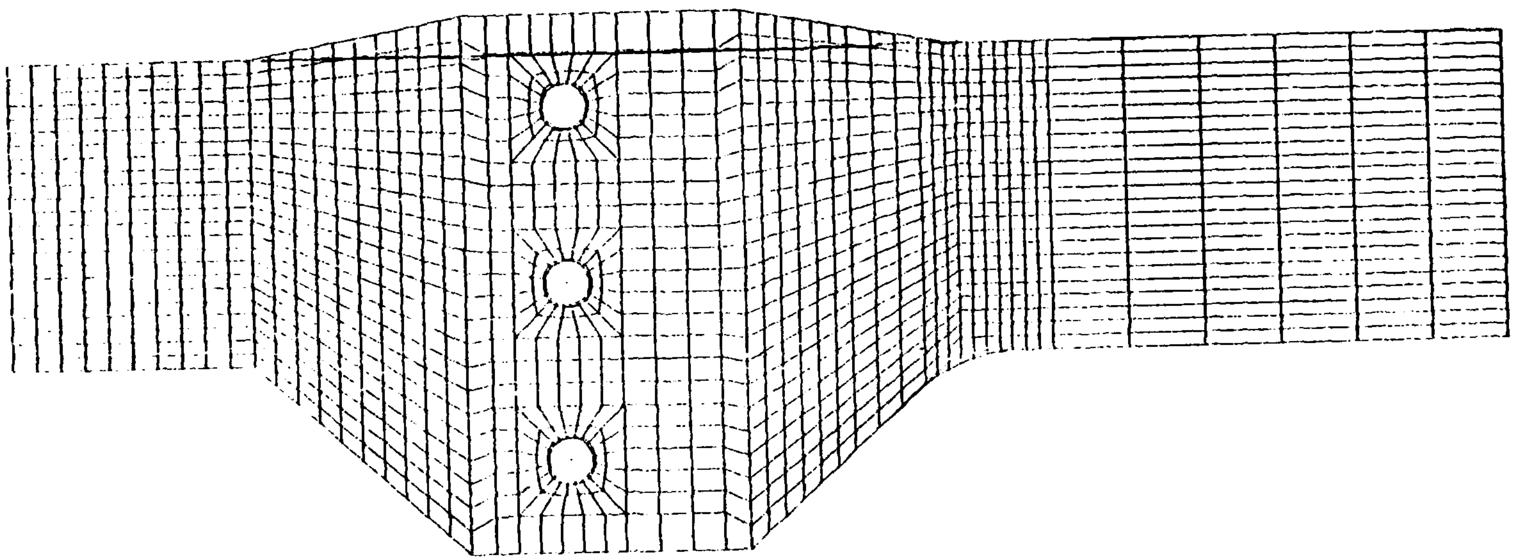


Figure 96. Finite Element Model of Torque Rib Spar Buildup.

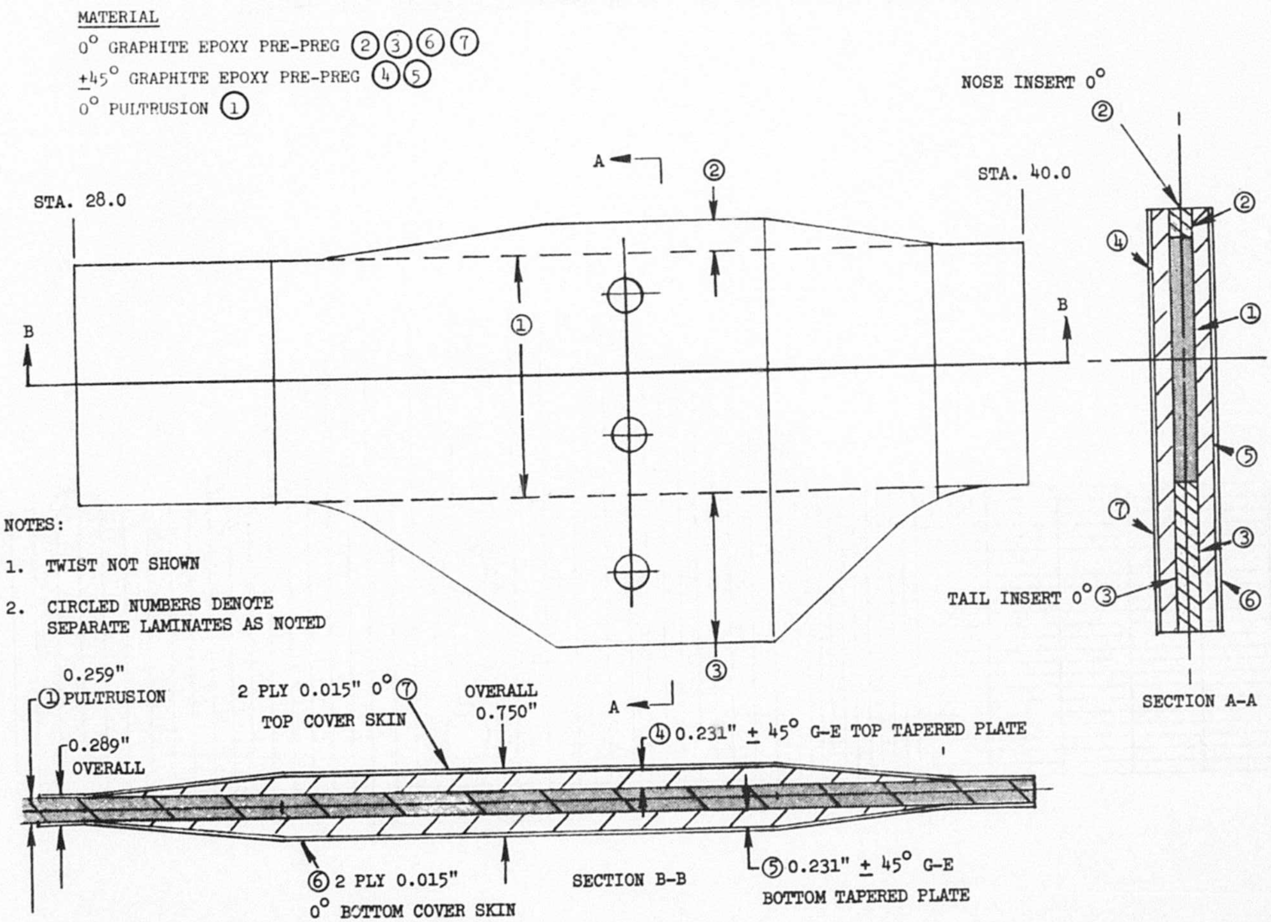


Figure 97. First Pultruded Spar Torque Rib Design, Concept III Selected for Fabrication, Testing, and Evaluation.

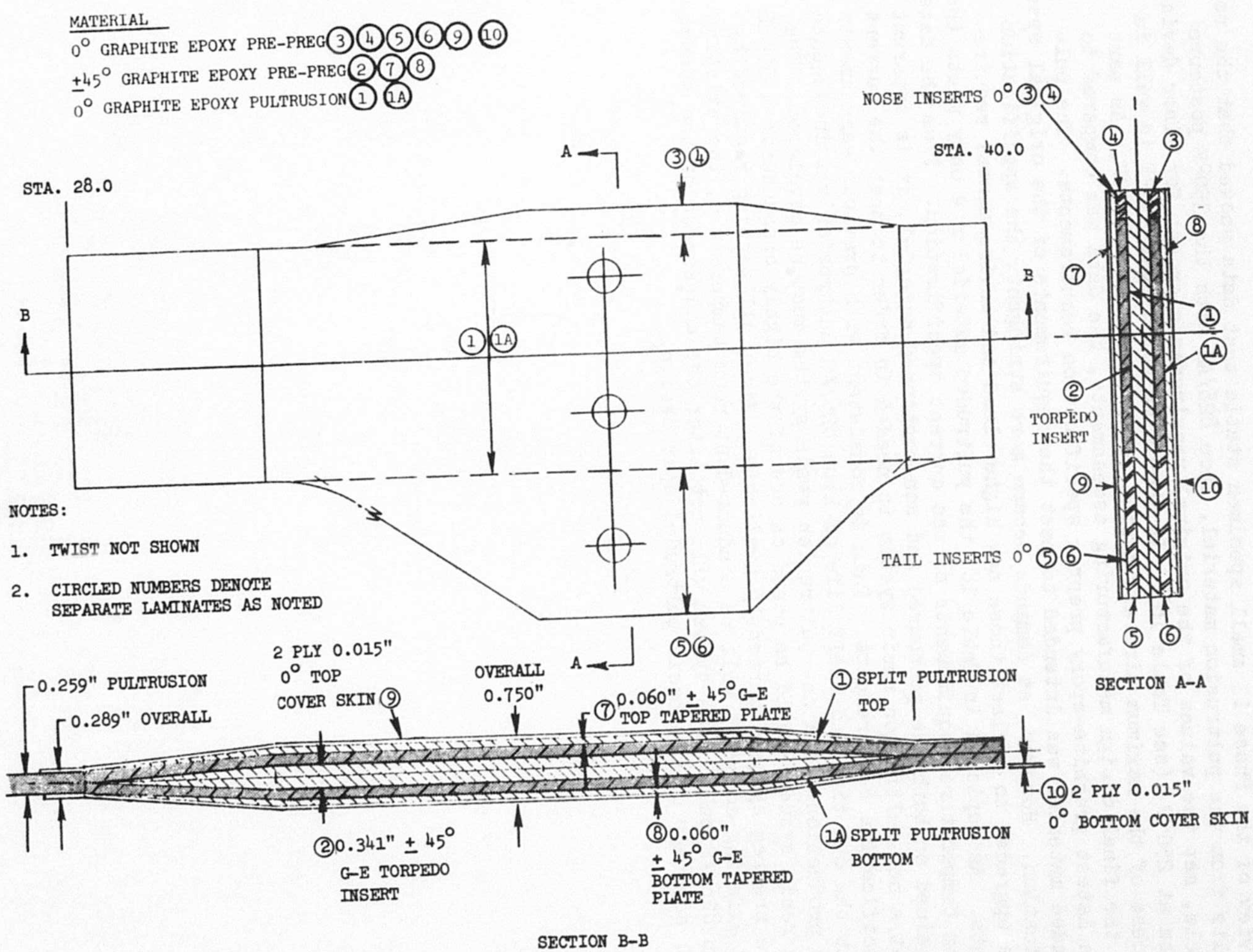
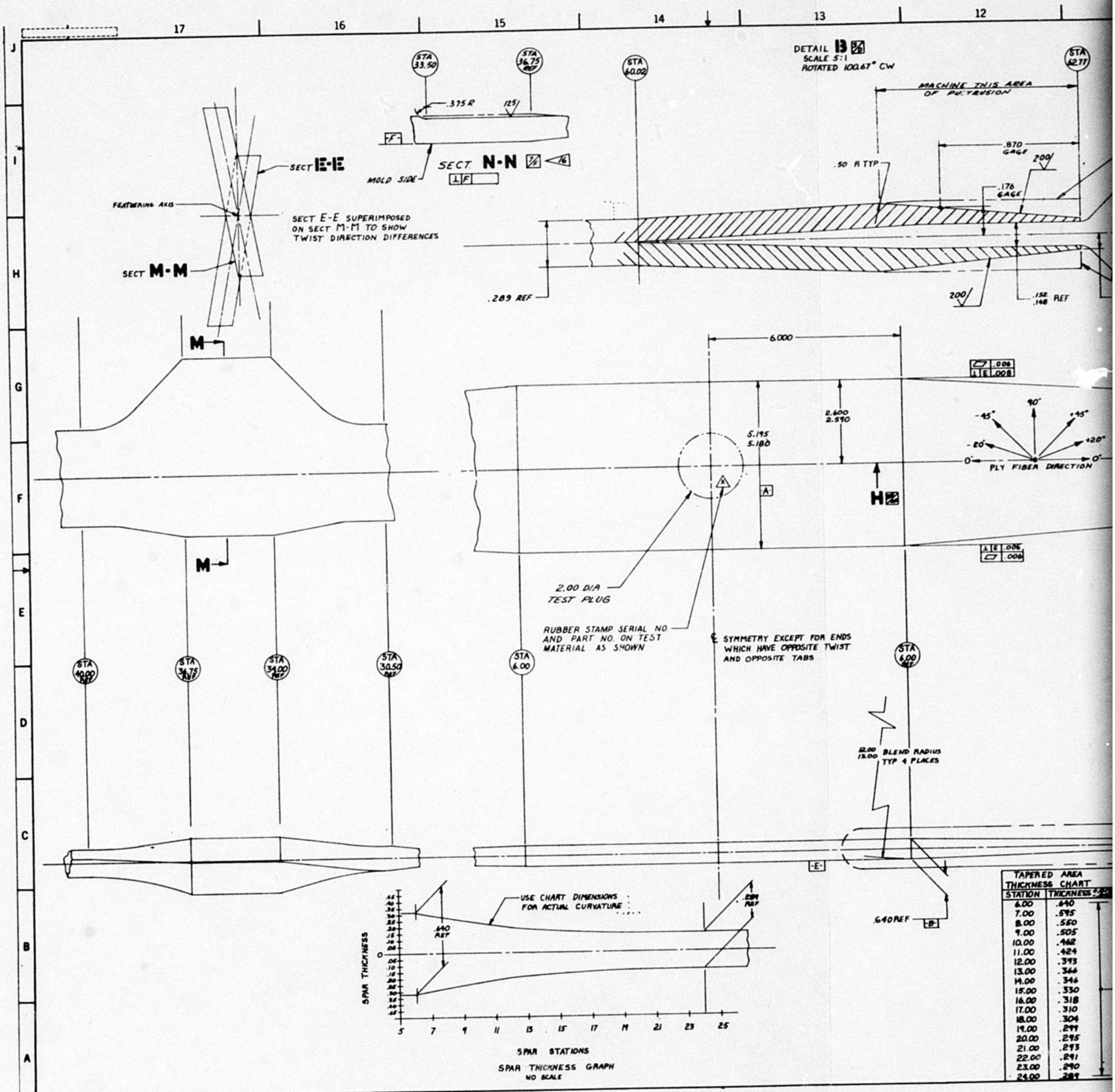


Figure 98. Second Pultruded Spar Torque Rib Design, Concept III Selected for Fabrication, Testing, and Evaluation.

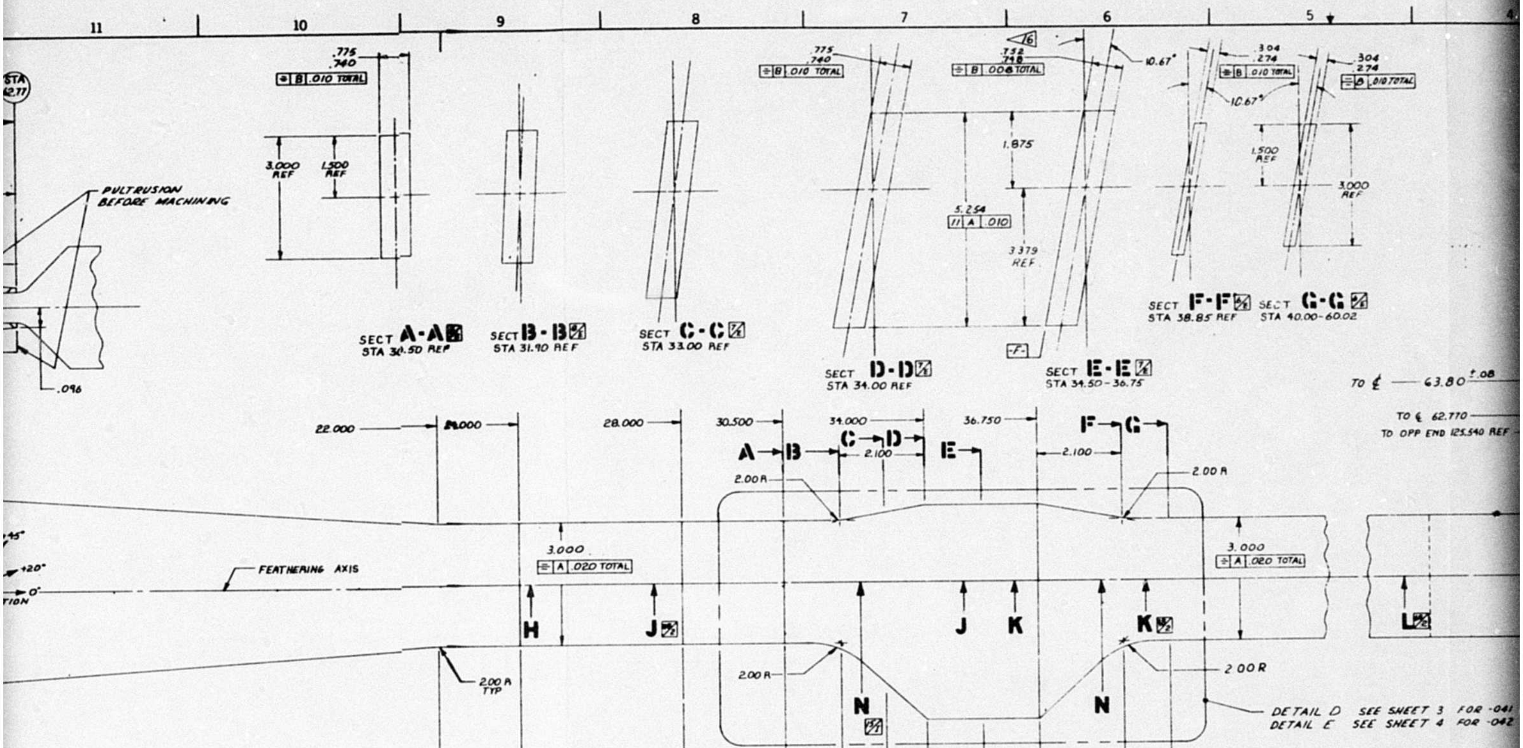
Review of Small Specimen Test Data

Review of the Phase II small specimen static test data showed that the results from the pultrusion material, Epon 826/AS with the 350°F postcure cycle, met the values of the original requirements except for minor deviation at 250°F (see Table 18). It should be noted that 250°F is well in excess of the maximum aircraft design requirements of + 165°F. As part of the final design manufacturing assessments, the data was compared to the latest graphite-epoxy prepreg specification requirements. The pultruded material was intended to meet the requirements of the original specification. However, as demands became more stringent, the specification was upgraded to reflect those new higher load and environmental requirements. As depicted in Table 18, the pultruded material now only meets the room temperature requirements of the current specification. From the data obtained on both the postcured and non-postcured material, it is apparent that a new pultrusion resin system is needed in order to meet the current specification requirements. This is consistent with previous assessments that the out time and shelf life of Epon 826/AS pultrusion was inadequate for production and a new pultrusion resin system must be developed. The new resin system should be based on one of the highly characterized 350°F cure prepreg systems currently available. Since all testing required by the existing contract will be conducted at room temperature, the existing Epon 826/AS pultrusion system will not alter the assessment of the structural adequacy of the basic pultruded spar design.

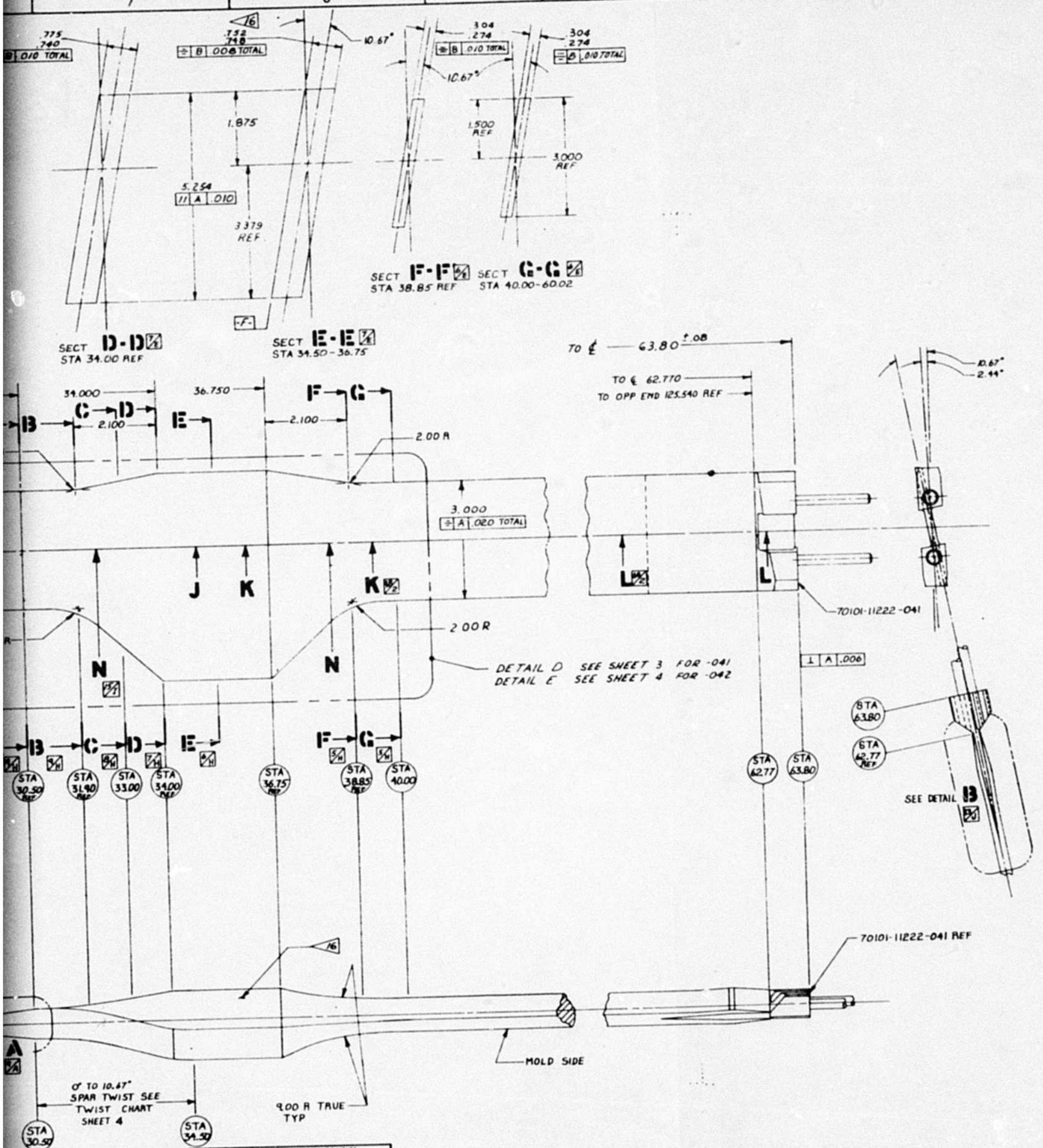


STATION	THICKNESS
6.00	.640
7.00	.595
8.00	.550
9.00	.505
10.00	.462
11.00	.424
12.00	.393
13.00	.366
14.00	.346
15.00	.330
16.00	.318
17.00	.310
18.00	.304
19.00	.299
20.00	.295
21.00	.293
22.00	.291
23.00	.290
24.00	.289

Figure 99. Proposed Full-Scale Production Pultruded Spar Drawing.



PULTRUSION BEFORE MACHINING
SECT A-A STA 30.50 REF
SECT B-B STA 31.90 REF
SECT C-C STA 33.00 REF
SECT D-D STA 34.00 REF
SECT E-E STA 34.50-36.75
SECT F-F STA 38.85 REF
SECT G-G STA 40.00-60.02
FEATHERING AXIS
DETAIL D SEE SHEET 3 FOR -041
DETAIL E SEE SHEET 4 FOR -042
TO ℄ 63.80
TO ℄ 62.770
TO OPP END 125.540 REF
041
042 SAME AS -041 EXCEPT AS SHOWN
SEE DETAIL C
STA 6.00-24.00 SEE SPAR THICKNESS CHART & GRAPH FOR CURVATURE
MOLD SIDE
SEE DETAIL A
0° TO 10.67° SPAR TWIST SEE TWIST CHART SHEET 4
9.00 R TRUE TYP
DETAIL A
9.000 R TYP 8 PLACES
APPLICATION OF PROTECTIVE FINISHES
APPLICABLE TO DASH NUMBERS
APPLICABLE INSPECTION TEST PLAN DRAWING NUMBER
38013-00005
1



NOTES

1. AFTER FABRICATION OF 041 & 042 MOLDED SPAR, MACHINE AS SHOWN IN DETAIL B. COMPLETE SPAR ASSY PER 70101-11202 AND IDENTIFY AS 38013-00005-041 & 042 SPAR ASSY
2. 200 ALL OVER EXCEPT AS NOTED. SS5100 SHALL APPLY FOR HOLES UNLESS OTHERWISE INDICATED. AREAS OF TRANSITION SHALL CONFORM TO THAT SPECIFIED FOR THE ROUGHEST ADJACENT FINISHED AREA UNLESS OTHERWISE INDICATED.
3. PLYS 101 THRU 250 TO BE GRAPHITE PREPREG TYPE HIGH STRENGTH "AS" FILAMENT, CONTINUOUS TAPE WITH NO SCRIM, NOMINAL THICKNESS .008 INCH 5209 NARMCO RESIN OTHERWISE IN GENERAL ACCORDANCE WITH SS9611-001
4. ALL SURFACES TO BE FREE OF NICKS, SCRATCHES AND TOOL MARKS.
5. PLIES 101, 102, 147 & 148 TO BE MADE FROM ONE CONTINUOUS PIECE OF COMPOSITE TAPE. NO JOINTS ALLOWED.
6. ALL PLY ENDS LOCATED BY STATION DIMS. TO BE ±.030
7. FIRST LAYER APPLIED AGAINST TOOL TO BE FLOROPEEL #3 (.002 THK) & MILTEX #3921 (.003 THK) OR EQUIV.
8. ANGULAR TOLERANCES TO BE ±0.083° ON TWIST.
9. PULTRUSION 044 SHALL BE PROCESSED IN ACCORDANCE WITH SES 701174.
10. REFER TO LE 70101-11201 FOR CONTOUR & TWIST.
11. TOLERANCES ON ORIENTATION OF 0° PLIES TO BE ±2°.
12. TOLERANCES ON ORIENTATION OF 20° & 45° PLIES TO BE ±5.
13. IMMEDIATELY PRIOR TO LAYUP REMOVE PEEL PLY FROM SURFACES OF 70101-11222-041 BKT ASSY
14. DURING LAYUP FIBER WASH ORIENTATION FROM FIBER ORIENTATION SHOWN TO BE ±.06 IN.
15. MAXIMUM GAP SEPARATION WITHIN A RIBBON TO BE .03 IN. AND TO OCCUR AT NO MORE THAN TWO PLACES WITHIN 2 IN. OF RIBBON WIDTH.
16. PLIES 204, 205 & 206 MAY BE MACHINED TO ACHIEVE .752/.748 DIM. AS SHOWN IN SECT. E-E ZONE GJ. MACHINE INDICATED SIDE ONLY AS SHOWN IN ZONE GC (DO NOT MACHINE MOLD SIDE OF SPAR.
17. SEE SHEET 4 FOR TWIST CHART.
18. SEE SHEET 2 FOR LAYUP SUB ASSYS

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SIKORSKY AIRCRAFT
DAAJ02-76-C-0001
PULTRUDED SPAR
J 78286 38013-00005

3

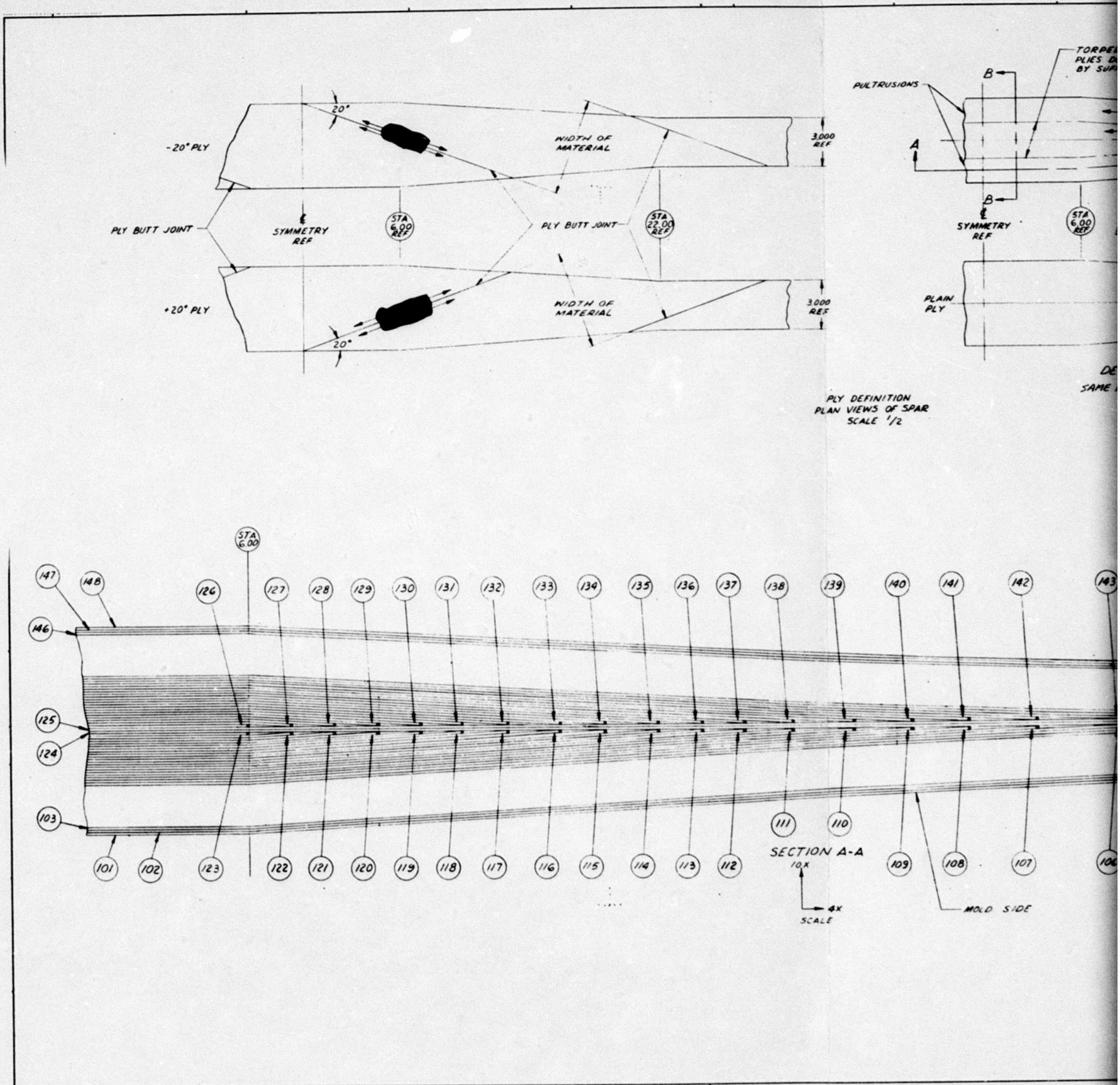

Figure 99. (Continued)

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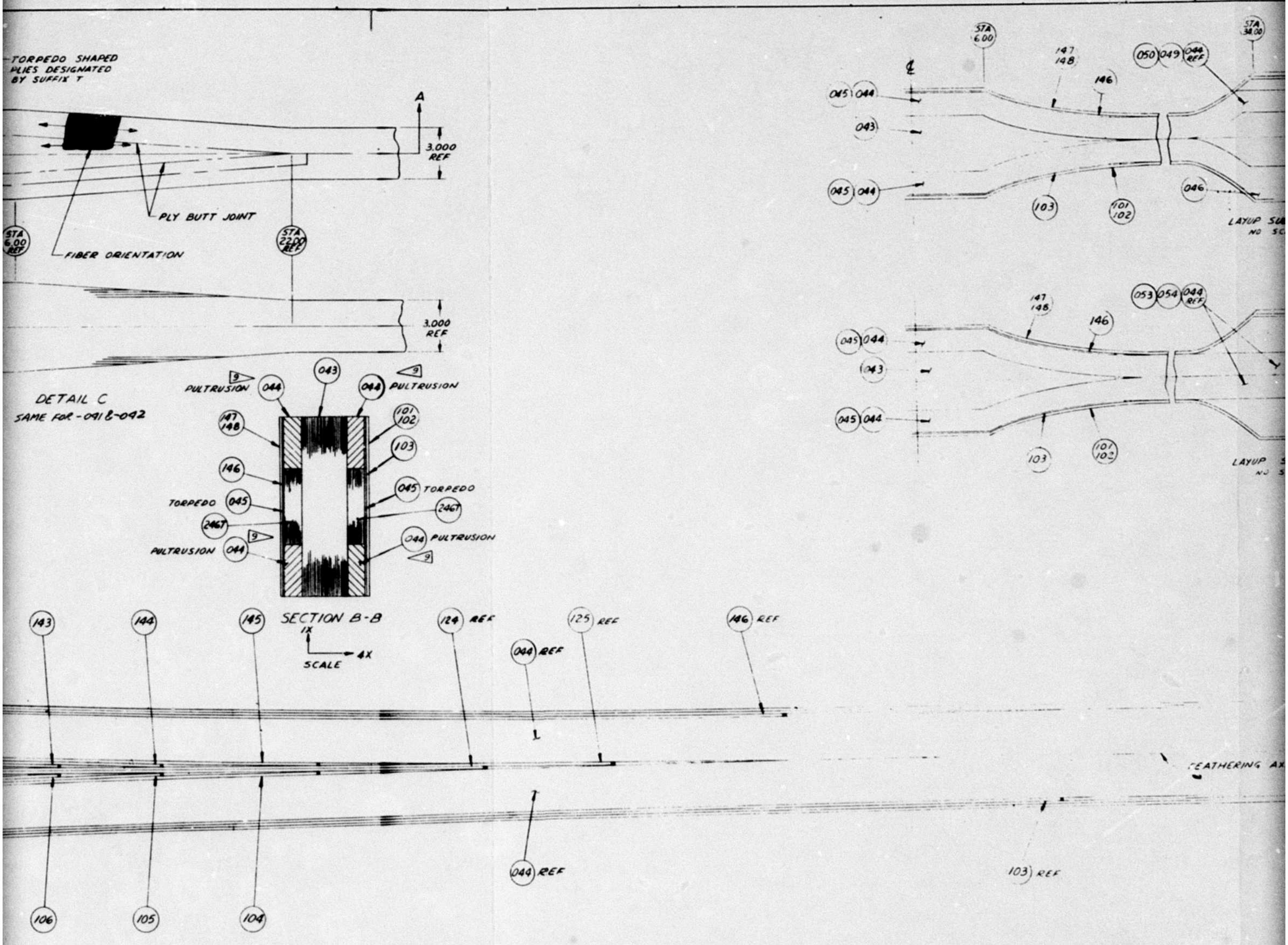
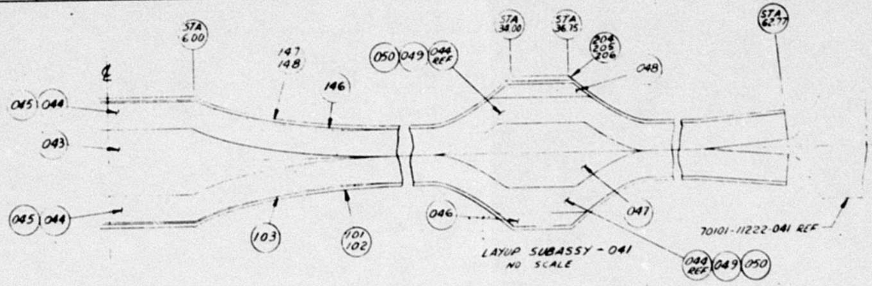


APPLICATION OF PROTECTIVE FINISHES APPLICABLE TO DASH NUMBERS						
FIN NO						
1						
2						
3						
4						
5						
SPEC	TREATMENT	FINISH NUMBER 1	2	3	4	5
MIL-A-8625	ANODIZE (TYPE I)					
TT-P-1757	PRIMER					
[illegible]	CHEM SURFACE TREAT					
QQ-P-416	CADMIUM PLATE (CL 2 TYPE II)					
[illegible]	IRREGULAR DISSIMILAR METALS ON ASSY. INST'L					
	TOUCH UP ON ASSY. INST'L					

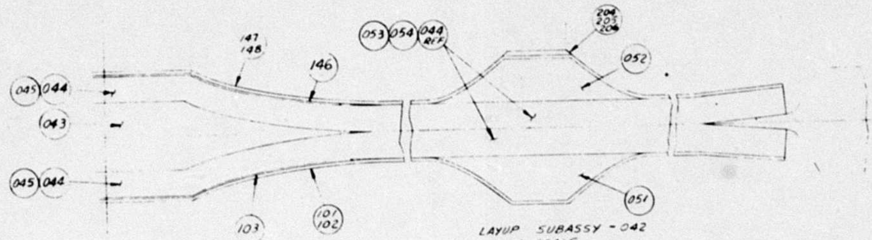
DASH NO	APPLICABLE INSPECTION TEST PLAN DRAWING NUMBER	DWG SHT NO	NOT REQUIRED	PENETRANT SS 8806	MAGNETIC SS 8805	RADIOGRAPHIC SS 8802	ULTRASONIC MIL-I-8950	ANODIZE BLEED MIL-I-8474	GRAIN BLEN SS 8705
INSPECTION REQUIREMENTS									

DWG NO 38013-00005 SHEET 2 REV

T QUALITY PRACTICABLE
SHED TO DDC



LAYUP SUBASSY - 041
NO SCALE



LAYUP SUBASSY - 042
NO SCALE

FOR NOTES SEE SH 1

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APPLICATION OF PROTECTIVE FINISHES

INSPECTION REQUIREMENTS

SIKORSKY AIRCRAFT
STRATFORD CONNECTICUT

ORIGINALLY PREPARED UNDER CONTRACT NUMBER DAAJ02-76-C-0001

DRAWING TITLE: PULTRUDED SPAR

SIZE	FSCM NO	DRAWING NUMBER	REV
J	78286	38013-00005	

SCALE NOTED — SHEET 2 of 4

3

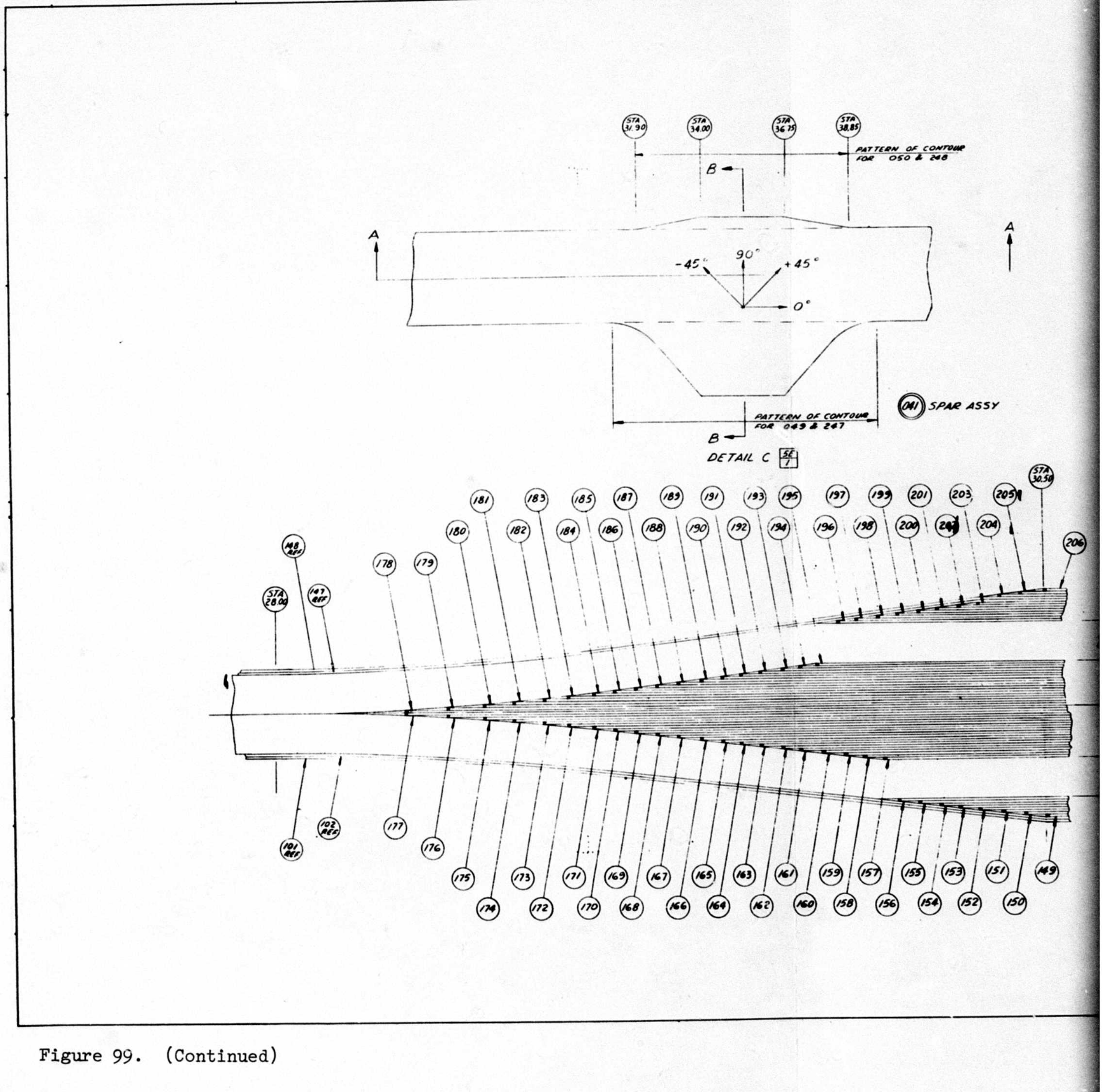

Figure 99. (Continued)

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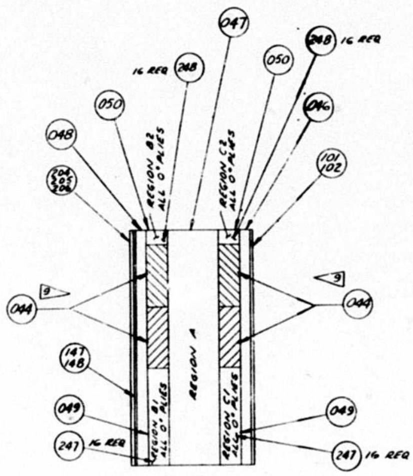


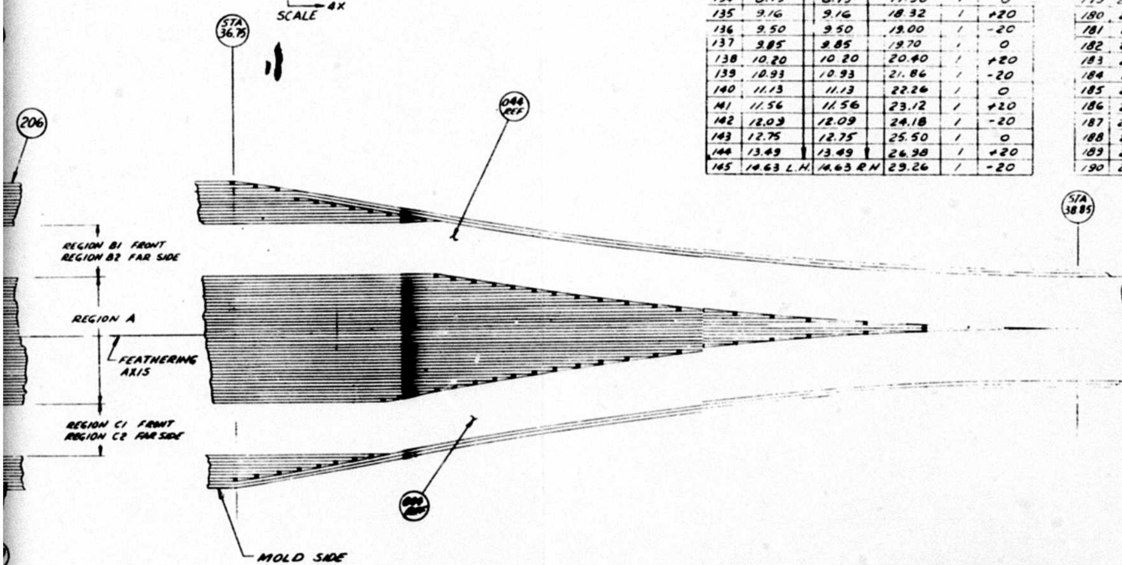
SECTION B-B
1X — 4X SCALE

PLY NO.	STATION WHERE PLY BEGINS	STATION WHERE PLY ENDS	TOTAL PLY LENGTH	QTY OF EACH PLY NO.	FIBER DIRECTION DEGREE
101	62.77 L.H.	62.77 R.H.	125.54	1	0
102	62.77	62.77	125.54	1	0
103	20.00	20.00	40.00	1	0
104	14.63	14.63	29.26	1	-20
105	13.49	13.49	26.98	1	+20
106	12.75	12.75	25.50	1	0
107	12.09	12.09	24.18	1	-20
108	11.56	11.56	23.12	1	+20
109	11.13	11.13	22.26	1	0
110	10.93	10.93	21.86	1	-20
111	10.20	10.20	20.40	1	+20
112	9.85	9.85	19.70	1	0
113	9.50	9.50	19.00	1	-20
114	9.16	9.16	18.32	1	+20
115	8.75	8.75	17.50	1	0
116	8.40	8.40	16.80	1	-20
117	8.00	8.00	16.00	1	+20
118	7.66	7.66	15.32	1	0
119	7.33	7.33	14.66	1	-20
120	7.00	7.00	14.00	1	+20
121	6.66	6.66	13.32	1	0
122	6.33	6.33	12.66	1	-20
123	6.00	6.00	12.00	1	+20
124	15.83	15.83	31.66	1	0
125	16.75	16.75	33.50	1	0
126	6.00	6.00	12.00	1	+20
127	6.33	6.33	12.66	1	-20
128	6.66	6.66	13.32	1	0
129	7.00	7.00	14.00	1	+20
130	7.33	7.33	14.66	1	-20
131	7.66	7.66	15.32	1	0
132	8.00	8.00	16.00	1	+20
133	8.40	8.40	16.80	1	-20
134	8.75	8.75	17.50	1	0
135	9.16	9.16	18.32	1	+20
136	9.50	9.50	19.00	1	-20
137	9.85	9.85	19.70	1	0
138	10.20	10.20	20.40	1	+20
139	10.93	10.93	21.86	1	-20
140	11.13	11.13	22.26	1	0
141	11.56	11.56	23.12	1	+20
142	12.09	12.09	24.18	1	-20
143	12.75	12.75	25.50	1	0
144	13.49	13.49	26.98	1	+20
145	14.63 L.H.	14.63 R.H.	29.26	1	-20

PLY LAYUP CHART

PLY NO.	STATION WHERE PLY BEGINS	STATION WHERE PLY ENDS	TOTAL PLY LENGTH	QTY OF EACH PLY NO.	FIBER DIRECTION DEGREE
146	18.00 LH.	18.00 RH.	36.00	1	0
147	62.77 LH	62.77 RH.	125.54	1	0
148	62.77 LH.	62.77 RH.	125.54	1	0
149	30.50	36.75	6.25	2	-45
150	30.43	36.80	6.37	2	+45
151	30.36	36.86	6.50	2	-45
152	30.28	36.91	6.63	2	+45
153	30.22	36.96	6.74	2	-45
154	30.15	37.00	6.85	2	+45
155	30.09	37.04	6.95	2	-45
156	30.02	37.09	7.07	2	+45
157	29.97	37.12	7.15	1	+45
158	29.91	37.16	7.25	1	-45
159	29.85	37.20	7.35	1	+45
160	29.78	37.25	7.47	1	-45
161	29.70	37.29	7.59	1	+45
162	29.64	37.34	7.70	1	-45
163	29.57	37.39	7.82	1	+45
164	29.50	37.44	7.94	1	-45
165	29.44	37.49	8.05	1	+45
166	29.37	37.54	8.17	1	-45
167	29.30	37.60	8.30	1	+45
168	29.23	37.65	8.42	1	-45
169	29.16	37.72	8.56	1	+45
170	29.10	37.79	8.69	1	-45
171	29.03	37.85	8.82	1	+45
172	28.95	37.93	8.98	1	-45
173	28.87	38.01	9.14	1	+45
174	28.77	38.10	9.33	1	-45
175	28.67	38.19	9.42	1	+45
176	28.56	38.33	9.77	1	-45
177	28.46	38.48	10.02	1	+45
178	28.46	38.48	10.02	1	+45
179	28.56	38.33	9.77	1	-45
180	28.67	38.19	9.42	1	+45
181	28.77	38.10	9.33	1	-45
182	28.87	38.01	9.14	1	+45
183	28.95	37.93	8.98	1	-45
184	29.03	37.85	8.82	1	+45
185	29.10	37.79	8.69	1	-45
186	29.16	37.72	8.56	1	+45
187	29.23	37.65	8.42	1	-45
188	29.30	37.60	8.30	1	+45
189	29.37	37.54	8.17	1	-45
190	29.44	37.49	8.05	1	+45

PLY NO.	STATION WHERE [illegible] BEGINS
191	29.5
192	29.5
193	29.6
194	29.7
195	29.7
196	29.8
197	29.8
198	29.9
199	30.0
200	30.0
201	30.1
202	30.2
203	30.2
204	30.3
205	30.42
206	30.50
207	29.96
208	29.90
209	29.83
210	29.76
211	29.70
212	29.63
213	29.55
214	29.49
215	29.43
216	29.37
217	29.30
218	29.23
219	29.15
220	29.09
221	29.01
222	28.94
223	28.86
224	28.78
225	28.67
226	28.54
227	28.35
228	28.35
229	28.54
230	28.67
231	28.78
232	28.86
233	28.94
234	29.01
235	29.09
236	29.15
237	29.23
238	29.30
239	29.37
240	29.43
241	29.49
242	29.55
243	29.63
244	29.70
245	29.76
2467	22.00
247	31.10
248	31.90
249	31.10
250	31.90



SECTION A-A
SCALE 10/1
(FOR -041 SPAR)

APPLICATION OF PROTECTIVE FINISHES
APPLICABLE TO DASH NUMBERS

FIN. NO | SPEC | TREATMENT | FINISH NUMBER

DASH NO | APPLICABLE INSPECTION TEST PLAN DRAWING NUMBER | DWG SHT NO

INSPECTION REQUIREMENTS

DWG NO 38013-00005 SHEET 3

PRACTICABLE

PLY LAYUP CHART

STATION WHERE PLY BEGINS	STATION WHERE PLY ENDS	TOTAL PLY LENGTH	QTY OF EACH PLY NO.	FIBER DIRECTION DEGREE
62.77L.H.	62.77R.H.	125.54	1	0
62.77	62.77	125.54	1	0
20.00	20.00	40.00	1	0
14.63	14.63	29.26	1	-20
13.49	13.49	26.98	1	+20
12.75	12.75	25.50	1	0
12.09	12.09	24.18	1	-20
11.56	11.56	23.12	1	+20
11.13	11.13	22.26	1	0
10.93	10.93	21.86	1	-20
10.20	10.20	20.40	1	+20
9.85	9.85	19.70	1	0
9.50	9.50	19.00	1	-20
9.16	9.16	18.32	1	+20
8.75	8.75	17.50	1	0
8.40	8.40	16.80	1	-20
8.00	8.00	16.00	1	+20
7.66	7.66	15.32	1	0
7.33	7.33	14.66	1	-20
7.00	7.00	14.00	1	+20
6.66	6.66	13.32	1	0
6.33	6.33	12.66	1	-20
6.00	6.00	12.00	1	+20
15.83	15.83	31.66	1	0
16.75	16.75	33.50	1	0
6.00	6.00	12.00	1	+20
6.33	6.33	12.66	1	-20
6.66	6.66	13.32	1	0
7.00	7.00	14.00	1	+20
7.33	7.33	14.66	1	-20
7.66	7.66	15.32	1	0
8.00	8.00	16.00	1	+20
8.40	8.40	16.80	1	-20
8.75	8.75	17.50	1	0
9.16	9.16	18.32	1	+20
9.50	9.50	19.00	1	20
9.85	9.85	19.70	1	0
10.20	10.20	20.40	1	+20
10.93	10.93	21.86	1	-20
11.13	11.13	22.26	1	0
11.56	11.56	23.12	1	+20
12.09	12.09	24.18	1	-20
12.75	12.75	25.50	1	0
13.49	13.49	26.98	1	+20
14.63 L.H.	14.63 R.H.	29.26	1	-20

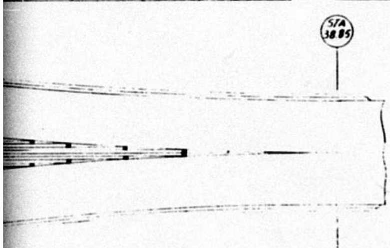
PLY LAYUP CHART

PLY NO.	STATION WHERE PLY BEGINS	STATION WHERE PLY ENDS	TOTAL PLY LENGTH	QTY OF EACH PLY NO.	FIBER DIRECTION DEGREE
146	18.00L.H.	18.00R.H.	36.00	1	0
147	62.77L.H.	62.77R.H.	125.54	1	0
148	62.77L.H.	62.77R.H.	125.54	1	0
149	30.50	36.75	6.25	2	-45
150	30.43	36.80	6.37	2	+45
151	30.36	36.86	6.50	2	-45
152	30.28	36.91	6.63	2	+45
153	30.22	36.96	6.74	2	-45
154	30.15	37.00	6.85	2	+45
155	30.03	37.04	6.95	2	-45
156	30.02	37.09	7.07	2	+45
157	29.97	37.12	7.15	1	+45
158	29.91	37.16	7.25	1	-45
159	29.85	37.20	7.35	1	+45
160	29.78	37.25	7.47	1	-45
161	29.70	37.29	7.59	1	+45
162	29.64	37.34	7.70	1	-45
163	29.57	37.39	7.82	1	+45
164	29.50	37.44	7.94	1	-45
165	29.44	37.49	8.05	1	+45
166	29.37	37.54	8.17	1	-45
167	29.30	37.60	8.30	1	+45
168	29.23	37.65	8.42	1	-45
169	29.16	37.72	8.56	1	+45
170	29.10	37.79	8.69	1	-45
171	29.03	37.85	8.82	1	+45
172	28.95	37.93	8.98	1	-45
173	28.87	38.01	9.14	1	+45
174	28.77	38.10	9.33	1	-45
175	28.67	38.19	9.42	1	+45
176	28.56	38.33	9.77	1	-45
177	28.46	38.48	10.02	1	+45
178	28.46	38.48	10.02	1	+45
179	28.56	38.33	9.77	1	-45
180	28.67	38.19	9.42	1	+45
181	28.77	38.10	9.33	1	-45
182	28.87	38.01	9.14	1	+45
183	28.95	37.93	8.98	1	-45
184	29.03	37.85	8.82	1	+45
185	29.10	37.79	8.69	1	-45
186	29.16	37.72	8.56	1	+45
187	29.23	37.65	8.42	1	-45
188	29.30	37.60	8.30	1	+45
189	29.37	37.54	8.17	1	-45
190	29.44	37.49	8.05	1	+45

PLY LAYUP CHART

PLY NO.	STATION WHERE PLY BEGINS	STATION WHERE PLY ENDS	TOTAL PLY LENGTH	QTY OF EACH PLY NO.	FIBER DIRECTION DEGREE
191	29.50	37.44	7.94	1	-45
192	29.57	37.39	7.82	1	+45
193	29.64	37.34	7.70	1	-45
194	29.70	37.29	7.59	1	+45
195	29.76	37.25	7.49	1	-45
196	29.83	37.22	7.39	2	+45
197	29.89	37.18	7.29	2	-45
198	29.96	37.13	7.17	2	+45
199	30.02	37.09	7.06	2	-45
200	30.09	37.04	6.95	2	+45
201	30.15	37.00	6.85	2	-45
202	30.22	36.96	6.74	2	+45
203	30.28	36.91	6.63	2	-45
204	30.35	36.86	6.51	2	90
205	30.42	36.80	6.38	2	0
206	30.50	36.75	6.25	2	90
207	29.96	37.13	7.17	1	+45
208	29.90	37.18	7.28	1	-45
209	29.83	37.22	7.39	1	+45
210	29.76	37.27	7.51	1	-45
211	29.70	37.31	7.61	1	+45
212	29.63	37.37	7.74	1	-45
213	29.55	37.42	7.87	1	+45
214	29.49	37.46	7.97	1	-45
215	29.43	37.51	8.08	1	+45
216	29.37	37.57	8.20	1	-45
217	29.30	37.63	8.33	1	+45
218	29.23	37.69	8.46	1	-45
219	29.15	37.75	8.60	1	+45
220	29.09	37.82	8.73	1	-45
221	29.01	37.88	8.87	1	+45
222	28.94	37.95	9.01	1	-45
223	28.86	38.02	9.16	1	+45
224	28.78	38.10	9.32	1	-45
225	28.67	38.20	9.53	1	+45
226	28.54	38.31	9.77	1	-45
227	28.39	38.49	9.90	1	+45
228	28.39	38.49	9.90	1	+45
229	28.54	38.31	9.77	1	-45
230	28.67	38.20	9.53	1	+45
231	28.78	38.10	9.32	1	-45
232	28.86	38.02	9.16	1	+45
233	28.94	37.95	9.01	1	-45
234	29.01	37.88	8.87	1	+45
235	29.09	37.82	8.73	1	-45
236	29.15	37.75	8.60	1	+45
237	29.23	37.69	8.46	1	-45
238	29.30	37.63	8.33	1	+45
239	29.37	37.57	8.20	1	-45
240	29.43	37.51	8.08	1	+45
241	29.49	37.46	7.97	1	-45
242	29.55	37.42	7.87	1	+45
243	29.63	37.37	7.74	1	-45
244	29.70	37.31	7.61	1	+45
245	29.76	37.27	7.51	1	-45
246T	22.00	22.00	44.00	32	0
247	31.10	39.60	8.50	32	0
248	31.90	38.85	6.95	32	0
249	31.10	39.60	8.50	32	0
250	31.90	38.85	6.95	32	0

FOR NOTES SEE SH 1



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APPLICATION OF PROTECTIVE FINISHES

APPLICABLE INSPECTION TEST PLAN DRAWING NUMBER

INSPECTION REQUIREMENTS

ORIGINALLY PREPARED UNDER CONTRACT NUMBER DAAJ02-76-C-0001

RELEASE AUTHORITY

SIKORSKY AIRCRAFT

STRATFORD CONNECTICUT

DRAWING TITLE: PULTRUDED SPAR

J | 78286 | 38013-00005

SHEET 3 OF 4

3

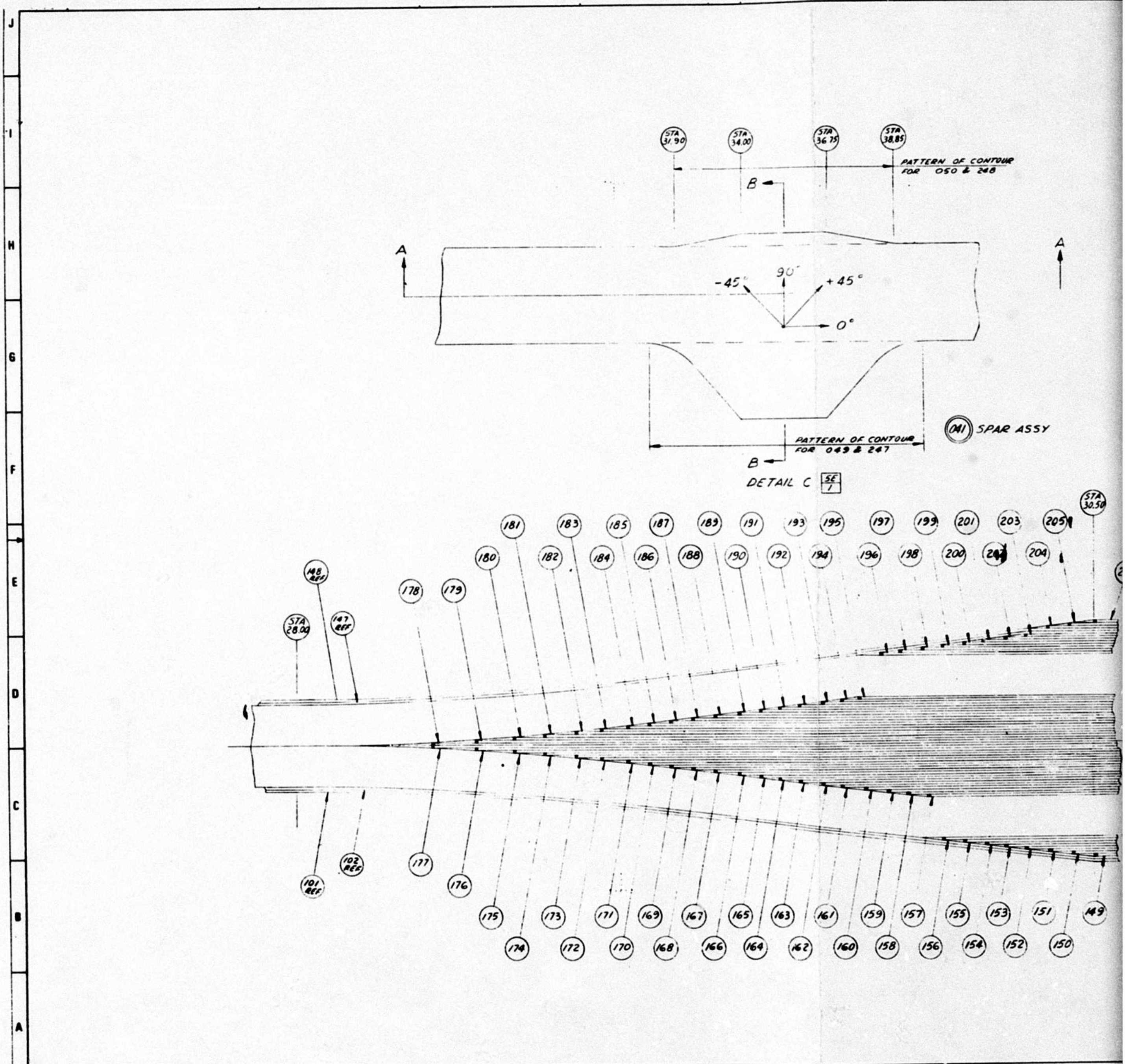

Figure 99. (Continued)

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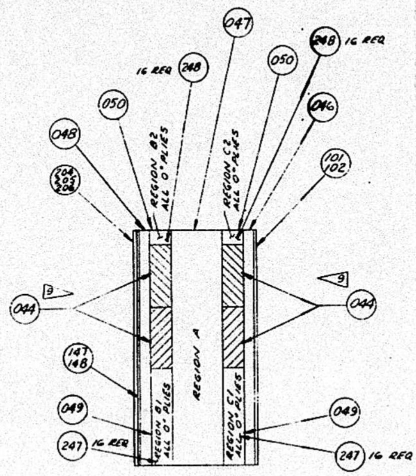
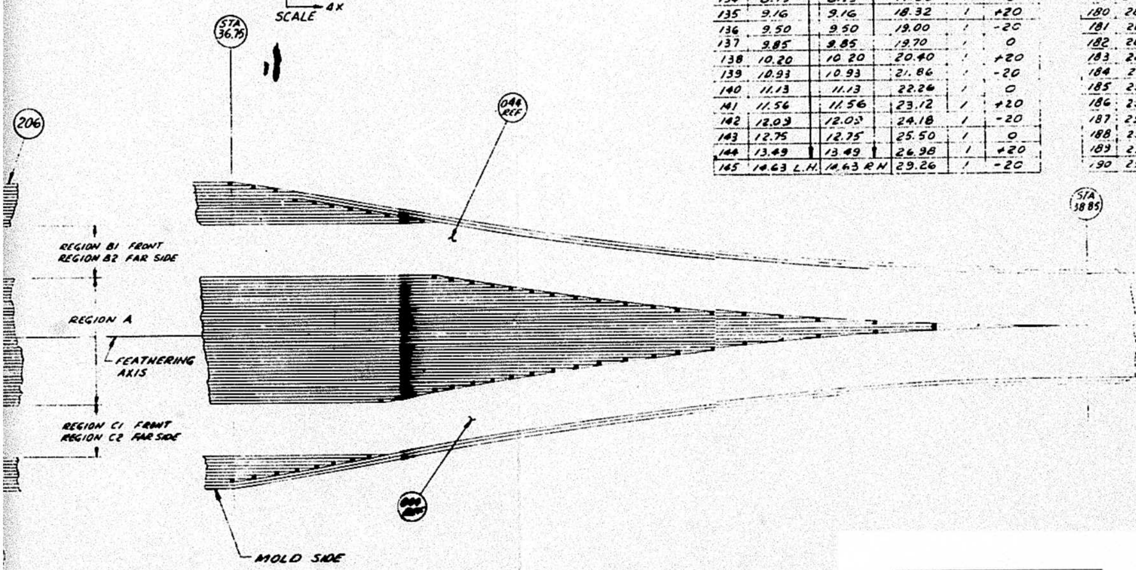


SECTION B-B
1X
4X
SCALE



SECTION A-A
SCALE 10/1
(FOR -041 SPAR)

PLY LAYUP CHART

PLY NO.	STATION WHERE PLY BEGINS	STATION WHERE PLY ENDS	TOTAL PLY LENGTH	QTY OF EACH PLY NO.	FIBER DIRECTION DEGREE
101	62.77 L.H.	62.77 R.H.	125.54	1	0
102	62.77	62.77	125.54	1	0
103	20.00	20.00	40.00	1	0
104	14.63	14.63	29.26	1	-20
105	13.49	13.49	26.98	1	+20
106	12.75	12.75	25.50	1	0
107	12.09	12.09	24.18		-20
108	11.56	11.56	23.12	1	+20
109	11.13	11.13	22.26	1	0
110	10.93	10.93	21.86	1	-20
111	10.20	10.20	20.40	1	+20
112	9.85	9.85	19.70	1	0
113	9.50	9.50	19.00	1	-20
114	9.16	9.16	18.32	1	+20
115	8.75	8.75	17.50	1	0
116	8.40	8.40	16.80	1	-20
117	8.00	8.00	16.00	1	+20
118	7.66	7.66	15.32	1	0
119	7.33	7.33	14.66	1	-20
120	7.00	7.00	14.00	1	+20
121	6.66	6.66	13.32	1	0
122	6.33	6.33	12.66	1	-20
123	6.00	6.00	12.00	1	+20
124	15.83	15.83	31.66	1	0
125	16.75	16.75	33.50	1	0
126	6.00	6.00	12.00	1	+20
127	6.33	6.33	12.66	1	-20
128	6.66	6.66	13.32	1	0
129	7.00	7.00	14.00	1	+20
130	7.33	7.33	14.66	1	-20
131	7.66	7.66	15.32	1	0
132	8.00	8.00	16.00	1	+20
133	8.40	8.40	16.80	1	-20
134	8.75	8.75	17.50	1	0
135	9.16	9.16	18.32	1	+20
136	9.50	9.50	19.00	1	-20
137	9.85	9.85	19.70	1	0
138	10.20	10.20	20.40	1	+20
139	10.93	10.93	21.86	1	-20
140	11.13	11.13	22.26	1	0
141	11.56	11.56	23.12	1	+20
142	12.09	12.09	24.18	1	-20
143	12.75	12.75	25.50	1	0
144	13.49	13.49	26.98	1	+20
145	14.63 L.H.	14.63 R.H.	29.26	1	-20

PLY LAYUP CHART

PLY NO.	STATION WHERE PLY BEGINS	STATION WHERE PLY ENDS	TOTAL PLY LENGTH	QTY OF EACH PLY NO.	FIBER DIRECTION DEGREE
146	18.00 L.H.	18.00 R.H.	36.00	1	0
147	62.77 L.H.	62.77 R.H.	125.54	1	0
148	62.77 L.H.	62.77 R.H.	125.54	1	0
149	30.50	36.75	6.25	2	-45
150	30.43	36.80	6.37	2	+45
151	30.36	36.86	6.50	2	-45
152	30.28	36.91	6.63	2	+45
153	30.22	36.96	6.74	2	-45
154	30.15	37.00	6.85	2	+45
155	30.09	37.04	6.95	2	-45
156	30.02	37.09	7.07	2	+45
157	29.97	37.12	7.15	1	+45
158	29.91	37.16	7.25	1	-45
159	29.85	37.20	7.35	1	+45
160	29.78	37.25	7.47	1	-45
161	29.70	37.29	7.59	1	+45
162	29.64	37.34	7.70	1	-45
163	29.57	37.39	7.82	1	+45
164	29.50	37.44	7.94	1	-45
165	29.44	37.49	8.05	1	+45
166	29.37	37.54	8.17	1	-45
167	29.30	37.60	8.30	1	+45
168	29.23	37.65	8.42	1	-45
169	29.16	37.72	8.56	1	+45
170	29.10	37.79	8.69	1	-45
171	29.03	37.85	8.82	1	+45
172	28.95	37.93	8.98	1	-45
173	28.87	38.01	9.14	1	+45
174	28.77	38.10	9.33	1	-45
175	28.67	38.19	9.42	1	+45
176	28.56	38.33	9.77	1	-45
177	28.46	38.48	10.02	1	+45
178	28.46	38.48	10.02	1	+45
179	28.56	38.33	9.77	1	-45
180	28.67	38.19	9.42	1	+45
181	28.77	38.10	9.33	1	-45
182	28.87	38.01	9.14	1	+45
183	28.95	37.93	8.98	1	-45
184	29.03	37.85	8.82	1	+45
185	29.10	37.79	8.69	1	-45
186	29.16	37.72	8.56	1	+45
187	29.23	37.65	8.42	1	-45
188	29.30	37.60	8.30	1	+45
189	29.37	37.54	8.17	1	-45
190	29.44	37.49	8.05	1	+45

PLY NO.	STATION WHERE... BEGINS
191	29.
192	29.
193	29.
194	29.
195	29.
196	29.
197	29.
198	29.
199	30.
200	30.
201	30.
202	30.
203	30.
204	30.
205	30.
206	30.
207	29.
208	29.
209	29.
210	29.7
211	29.7
212	29.
213	29.5
214	29.
215	29.
216	29.
217	29.
218	29.
219	29.
220	29.
221	29.
222	28.
223	28.
224	28.
225	28.
226	28.
227	28.
228	28.
229	28.
230	28.
231	28.
232	28.
233	28.
234	29.
235	29.
236	29.
237	29.
238	29.
239	29.
240	29.
241	29.
242	29.
243	29.
244	29.
245	29.
246T	28.
247	31.
248	31.
249	31.
250	31.

APPLICATION OF PROTECTIVE FINISHES APPLICABLE TO DASH NUMBERS

DASH NO. | APPLICABLE INSPECTION TEST PLAN DRAWING NUMBER

INSPECTION REQUIREMENTS

38013-00005 | SHEET 3

RACTICABLE

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PLY LAYUP CHART

PLY NO.	STATION WHERE PLY BEGINS	STATION WHERE PLY ENDS	TOTAL PLY LENGTH	QTY OF EACH PLY NO.	FIBER DIRECTION DEGREE
101	62.77 L.H.	62.77 R.H.	125.54	1	0
102	62.77	62.77	125.54	1	0
103	20.00	20.00	40.00	1	0
104	14.63	14.63	29.26	1	-20
105	13.49	13.49	26.98	1	+20
106	12.75	12.75	25.50	1	0
107	12.09	12.09	24.18	1	-20
108	11.56	11.56	23.12	1	+20
109	11.13	11.13	22.26	1	0
110	10.93	10.93	21.86	1	-20
111	10.20	10.20	20.40	1	+20
112	9.85	9.85	19.70	1	0
113	9.50	9.50	19.00	1	-20
114	9.16	9.16	18.32	1	+20
115	8.75	8.75	17.50	1	0
116	8.40	8.40	16.80	1	-20
117	8.00	8.00	16.00	1	+20
118	7.66	7.66	15.32	1	0
119	7.33	7.33	14.66	1	-20
120	7.00	7.00	14.00	1	+20
121	6.66	6.66	13.32	1	0
122	6.33	6.33	12.66	1	-20
123	6.00	6.00	12.00	1	+20
124	15.83	15.83	31.66	1	0
125	16.75	16.75	33.50	1	0
126	6.00	6.00	12.00	1	+20
127	6.33	6.33	12.66	1	-20
128	6.66	6.66	13.32	1	0
129	7.00	7.00	14.00	1	+20
130	7.33	7.33	14.66	1	-20
131	7.66	7.66	15.32	1	0
132	8.00	8.00	16.00	1	+20
133	8.40	8.40	16.80	1	-20
134	8.75	8.75	17.50	1	0
135	9.16	9.16	18.32	1	+20
136	9.50	9.50	19.00	1	-20
137	9.85	9.85	19.70	1	0
138	10.20	10.20	20.40	1	+20
139	10.93	10.93	21.86	1	-20
140	11.13	11.13	22.26	1	0
141	11.56	11.56	23.12	1	+20
142	12.09	12.09	24.18	1	-20
143	12.75	12.75	25.50	1	0
144	13.49	13.49	26.98	1	+20
145	14.63 L.H.	14.63 R.H.	29.26	1	-20

PLY LAYUP CHART

PLY NO.	STATION WHERE PLY BEGINS	STATION WHERE PLY ENDS	TOTAL PLY LENGTH	QTY OF EACH PLY NO.	FIBER DIRECTION DEGREE
146	18.00 LH	18.00 RH	36.00	1	0
147	62.77 LH	62.77 R.H.	125.54	1	0
148	62.77 LH	62.77 R.H.	125.54	1	0
149	30.50	36.75	6.25	2	-45
150	30.43	36.80	6.37	2	+45
151	30.36	36.86	6.50	2	-45
152	30.28	36.91	6.63	2	+45
153	30.22	36.96	6.74	2	-45
154	30.15	37.00	6.85	2	+45
155	30.09	37.04	6.95	2	-45
156	30.02	37.09	7.07	2	+45
157	29.97	37.12	7.15	1	+45
158	29.91	37.16	7.25	1	-45
159	29.85	37.20	7.35	1	+45
160	29.78	37.25	7.47	1	-45
161	29.70	37.29	7.59	1	+45
162	29.64	37.34	7.70	1	-45
163	29.57	37.39	7.82	1	+45
164	29.50	37.44	7.94	1	-45
165	29.44	37.49	8.05	1	+45
166	29.37	37.54	8.17	1	-45
167	29.30	37.60	8.30	1	+45
168	29.23	37.65	8.42	1	-45
169	29.16	37.72	8.56	1	+45
170	29.10	37.79	8.69	1	-45
171	29.03	37.85	8.82	1	+45
172	28.95	37.93	8.98	1	-45
173	28.87	38.01	9.14	1	+45
174	28.77	38.10	9.33	1	-45
175	28.67	38.19	9.42	1	+45
176	28.56	38.33	9.77	1	-45
177	28.46	38.48	10.02	1	+45
178	28.46	38.48	10.02	1	+45
179	28.56	38.33	9.77	1	-45
180	28.67	38.19	9.42	1	+45
181	28.77	38.10	9.33	1	-45
182	28.87	38.01	9.14	1	+45
183	28.95	37.93	8.98	1	-45
184	29.03	37.85	8.82	1	+45
185	29.10	37.79	8.69	1	-45
186	29.16	37.72	8.56	1	+45
187	29.23	37.65	8.42	1	-45
188	29.30	37.60	8.30	1	+45
189	29.37	37.54	8.17	1	-45
190	29.44	37.49	8.05	1	+45

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PLY LAYUP CHART

PLY NO.	STATION WHERE PLY BEGINS	STATION WHERE PLY ENDS	TOTAL PLY LENGTH	QTY OF EACH PLY NO.	FIBER DIRECTION DEGREE
191	29.50	37.44	7.94	1	-45
192	29.57	37.39	7.82	1	+45
193	29.64	37.34	7.70	1	-45
194	29.70	37.29	7.59	1	+45
195	29.76	37.25	7.49	1	-45
196	29.83	37.22	7.39	2	+45
197	29.89	37.18	7.29	2	-45
198	29.96	37.13	7.17	2	+45
199	30.02	37.09	7.06	2	-45
200	30.09	37.04	6.95	2	+45
201	30.15	37.00	6.85	2	-45
202	30.22	36.96	6.74	2	+45
203	30.28	36.91	6.63	2	-45
204	30.35	36.86	6.51	2	90
205	30.42	36.80	6.38	2	0
206	30.50	36.75	6.25	2	90
207	29.96	37.13	7.17	1	+45
208	29.90	37.18	7.28	1	-45
209	29.83	37.22	7.39	1	+45
210	29.76	37.27	7.51	1	-45
211	29.70	37.31	7.61	1	+45
212	29.63	37.37	7.74	1	-45
213	29.55	37.42	7.87	1	+45
214	29.49	37.46	7.97	1	-45
215	29.43	37.51	8.08	1	+45
216	29.37	37.57	8.20	1	-45
217	29.30	37.63	8.33	1	+45
218	29.23	37.69	8.46	1	-45
219	29.15	37.75	8.60	1	+45
220	29.09	37.82	8.73	1	-45
221	29.01	37.88	8.87	1	+45
222	28.94	37.95	9.01	1	-45
223	28.86	38.02	9.16	1	+45
224	28.78	38.10	9.32	1	-45
225	28.67	38.20	9.53	1	+45
226	28.54	38.31	9.77	1	-45
227	28.39	38.49	9.90	1	+45
228	28.39	38.49	9.90	1	+45
229	28.54	38.31	9.77	1	-45
230	28.67	38.20	9.53	1	+45
231	28.78	38.10	9.32	1	-45
232	28.86	38.02	9.16	1	+45
233	28.94	37.95	9.01	1	-45
234	29.01	37.88	8.87	1	+45
235	29.09	37.82	8.73	1	-45
236	29.15	37.75	8.60	1	+45
237	29.23	37.69	8.46	1	-45
238	29.30	37.63	8.33	1	+45
239	29.37	37.57	8.20	1	-45
240	29.43	37.51	8.08	1	+45
241	29.49	37.46	7.97	1	-45
242	29.55	37.42	7.87	1	+45
243	29.63	37.37	7.74	1	-45
244	29.70	37.31	7.61	1	+45
245	29.76	37.27	7.51	1	-45
246T	22.00	22.00	44.00	32	0
247	31.10	39.60	8.50	32	0
248	31.90	38.85	6.95	32	0
249	31.10	39.60	8.50	32	0
250	31.90	38.85	6.95	32	0

FOR NOTES SEE SH 1

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APPLICATION OF PROTECTIVE FINISHES
APPLICABLE TO DASH NUMBERS

INSPECTION REQUIREMENTS

DAAJ02-76-C-0001

SIKORSKY AIRCRAFT

PULTRUDED SPAR

J | 78286 | 38013-00005

SHEET 3 OF 4

38013-00005

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TABLE 18. PHASE II SMALL SPECIMEN STATIC TEST RESULTS AND COMPARISON TO GRAPHITE-EPOXY PREPREG SPECIFICATION REQ

TEST	ORIGINAL REQUIREMENTS Graphite-Epoxy Prepreg Spec 9-3-74				CURRENT REQUIREMENTS Graphite-Epoxy (4-18-78)				EPON 826/AS PULTRU			
									Postcured (a) 0.063" Mat'l. @ 60% V_f			
	-65°F	R.T.	160°F	250°F	-65°F	R.T.	160°F	250°F	-65°F	R.T.	160°F	250°F
FLEXURAL STRENGTH (Ksi)	95% R.T.Min. Values	200 Min. Avg.	70% R.T.Min. Values	65% R.T.Min. Values	200 Min.	200 Min.	200 Min.	160 Min.	--- --- --- --- ---	284 280 280 264 253 Avg. 272	225 214 211 201 --- Avg. 213 (78% R.T.)	131 126 126 --- --- Avg. 130 (48% R.T.)
FLEXURAL MODULUS (Psi X 10^6)	95 to 1.05% R.T.Min. Values	16 to 18 (Avg.)	Min. of 95% of R.T.Avg. Value	Min. of 65% of R.T.Avg. Value	16 to 19 (Avg.)	16 to 19 (Avg.)	16 to 19 (Avg.)	15 Min. (Avg.)	--- --- --- --- ---	17.6 17.4 17.1 17.0 16.4 Avg.17.1	16.7 16.0 15.7 14.8 ---- Avg. 15.8 (93% R.T.)	13.7 13.4 13.1 ---- ---- Avg.13.4 (78% R.T.)
INTERLAMINAR SHEAR STRENGTH (Psi)	Min. of 95% of R.T. Avg. Values	12,000 Min. Avg.	Min. of 70% of R.T.Avg. Value	Min. of 65% of R.T.Avg. Value	13,000 Min.	13,000 Min.	12,000 Min.	10,000 Min.	--- --- --- --- ---	14,300 14,100 13,300 13,200 13,000 Avg.13,600	12,400 11,600 11,300 --- --- Avg.11,700 (86% R.T.)	7,700 7,600 7,500 --- --- Avg.7,600 (56% R.T.)
TENSILE STRENGTH (Ksi)	No Reqmt.	No Reqmt.	No Reqmt.	No Reqmt.	170 Min.	170 Min.	170 Min.	No Reqmt.	230 190 180 170 --- --- --- --- --- --- Avg. 192	200 196 187 170 --- --- --- --- --- --- Avg. 188	197 193 191 175 --- --- --- --- --- --- Avg. 189	--- --- --- --- --- --- --- --- --- ---
TENSILE MODULUS (Psi X 10^6)	No Reqmt.	No Reqmt.	No Reqmt.	No Reqmt.	17 to 20 (Avg.)	17 to 20 (Avg.)	17 to 20 (Avg.)	No Reqmt.	17.1 17.4 19.0 18.4 Avg. 18	17.6 18.0 18.1 17.4 Avg.17.8	17.9 18.1 17.2 18.3 Avg.17.9	16.6 19.4 18.7 17.1 Avg.18.1
COMPRESSION STRENGTH (Ksi)	No Reqmt.	No Reqmt.	No Reqmt.	No Reqmt.	No Reqmt.	170 Min.	No Reqmt.	No Reqmt.	---	---	---	---
COMPRESSION MODULUS (Psi X 10^6)	No Reqmt.	No Reqmt.	No Reqmt.	No Reqmt.	No Reqmt.	15 Min. (Avg.)	No Reqmt.	No Reqmt.	---	---	---	---
TRANSVERSE TENSILE STRAIN, u in./in.	No Reqmt.	4000	No Reqmt.	No Reqmt.	No Reqmt.	4000	4000	No Reqmt.	---	---	---	---

(a) Cured 1 hour at 400°F followed by postcure of 1 hour at 200°F + 2 hours.

(b) Cured 1 hour at 400°F.

SPECIMEN STATIC TEST RESULTS AND COMPARISON TO GRAPHITE-EPOXY PREPREG SPECIFICATION REQUIREMENTS

CURRENT REQUIREMENTS Graphite-Epoxy (4-18-78)				EPON 826/AS PULTRUSION TEST DATA							
				Postcured 0.063" Mat'l. @ 60% V_f (a)				No Postcure .100 " Mat'l. @ 60% V_f (b)			
-65°F	R.T.	160°F	250°F	-65°F	R.T.	160°F	250°F	-65°F	R.T.	160°F	250°F
200 Min.	200 Min.	200 Min.	160 Min.	--- --- --- --- ---	284 280 280 264 253 Avg. 272	225 214 211 201 --- Avg. 213 (78% R.T.)	131 126 126 --- --- Avg. 130 (48% R.T.)	143 227 221 220 219 Avg. 223	232 229 205 199 194 Avg. 212	170 165 150 148 140 Avg. 155	93 71 69 68 67 Avg. 74
6 to 19 (Avg.)	16 to 19 (Avg.)	16 to 19 (Avg.)	15 Min. (Avg.)	--- --- --- --- ---	17.6 17.4 17.1 17.0 16.4 Avg.17.1	16.7 16.0 15.7 14.8 ---- Avg. 15.8 (93% R.T.)	13.7 13.4 13.1 ---- ---- Avg.13.4 (78% R.T.)	17.2 17.1 16.7 16.4 15.9 Avg.16.7	17.1 16.9 16.9 16.7 16.1 Avg.16.4	15.8 15.7 15.2 12.4 10.0 Avg.13.8	10.0 9.4 8.1 7.7 7.2 Avg.8.5
13,000 Min.	13,000 Min.	12,000 Min.	10,000 Min.	--- --- --- --- ---	14,300 14,100 13,300 13,200 13,000 Avg.13,600	12,400 11,600 11,300 --- --- Avg. 11,700 (86% R.T.)	7,700 7,600 7,500 --- --- Avg.7,600 (56% R.T.)	20,200 18,600 18,400 17,700 16,300 Avg. 18,300	14,500 14,300 14,200 13,800 13,700 Avg.14,100	9,900 9,700 9,400 9,200 8,800 Avg.9,400	6,400 6,100 6,000 6,000 5,700 Avg. 6,400
170 Min.	170 Min.	170 Min.	No Reqmt.	230 190 180 170 --- --- --- --- --- --- Avg. 192	200 196 187 170 --- --- --- --- --- --- Avg. 188	197 193 191 175 --- --- --- --- --- --- Avg. 189	--- --- --- --- --- --- --- --- --- ---	--- --- --- --- --- --- --- --- --- ---	250 242 232 227 217 211 202 180 173 162 Avg. 210	203 200 189 179 --- --- --- --- --- --- Avg. 193	--- --- --- --- --- --- --- --- --- ---
17 to 20 (Avg.)	17 to 20 (Avg.)	17 to 20 (Avg.)	No Reqmt.	17.1 17.4 19.0 18.4 Avg. 18	17.6 18.0 18.1 17.4 Avg.17.8	17.9 18.1 17.2 18.3 Avg.17.9	16.6 19.4 18.7 17.1 Avg.18.1	--- --- --- --- ---	20.6 18.8 19.7 17.9 Avg. 19.3	--- --- --- --- ---	--- --- --- --- ---
No Reqmt.	170 Min.	No Reqmt.	No Reqmt.	---	---	---	---	---	---	---	---
No Reqmt.	15 Min. (Avg.)	No Reqmt.	No Reqmt.	---	---	---	---	---	---	---	---
No Reqmt.	4000	4000	No Reqmt.	---	---	---	---	---	3800	---	---

ure of 1 hour at 200°F + 2 hours.

Manufacturing and Material Cost Comparison

The manufacturing and material cost comparison generated for this program considered the variable recurring manufacturing operations and material costs for the current UH-60A BLACK HAWK production prepreg spar and the two proposed pultrusion spar designs. The common manufacturing operations for which the times would be identical were not included in the cost comparison. Table 19 summarizes the cost comparison and Table 20 provides the details of the pultruded design breakdown.

The results indicate that a cost savings of $1,576 per aircraft would be obtained by incorporation of either pultruded design concept in place of the existing production prepreg design. This would be a total cost savings of $1,960,000 if the pultruded spar design were substantiated and incorporated as originally planned.

TABLE 19. SUMMARY - COST COMPARISON, BLACK HAWK PRODUCTION AND PULTRUDED DESIGN TAIL ROTOR SPARS

	ITEM	Existing BLACK HAWK Production Spar, P/N-70101-11201			Pultruded Spars P/N-38013-00005 -041/-042		
		Quantity Req'd/Spar	Manhours Per Spar	Equiv. $/Spar (a)	Quantity Req'd/Spar	Manhours Per Spar	Equiv. $/Spar (a)
Labor	Cut, mark & package Prepare Material	46(L) 47(M) 143(S) 236 plys	12 (b)	$ 480	4(L) 42(M) 115(S) 161 pcs.	7 (b)(c)	$ 280
Labor	Lay up Prepreg Material	236 plys	16.4 (d)	$ 656	161 pcs.	8.5 (d)(e)	$ 340
Labor	Lay up Pultrusion	--	--	--	4 pcs.	1.	$ 40
Labor	Setup & Machine Tip End	--	--	--	4 cuts	3.5	$ 140
Labor	TOTAL LABOR →		28.4 hr	= $1136		20 hr =	$ 800
Material	Prepreg ($54/lb)	20 lb	--	$1436 (f)	10 lb	--	$ 718 (e)
Material	Pultrusion	--	--	--	8 lb	--	$ 266 (f)
Material	TOTAL MATERIAL (f) →	--	--	$1436	--	--	$ 984
Labor & Material	TOTAL COST Per Spar (g) (i) →			$2572			$1784 (i)

Δ Savings/Spar = $788/Spar

Δ Savings/Aircraft = $1576 (2 Spars/Aircraft)

Total Projected Savings = $1,960,000 (1247 Aircraft) (h)

(Notes for Table 19 on next page)

<u>Notes for Table 19</u>

(a) Labor rate of $40/hr used. Assumed 1978 industry typical labor rate with overhead and G & A costs.

(b) Large (L) = 8 min/ply
Medium (M) = 4 min/ply
Small (S) = 1.15 min/ply

(c) -045, -049, -050, -053, and -054 cut in packages of 16 pieces requires additional layup time of 1.5 hours on Gerber machine. Refer to Table 20 for dash number identification.

(d) Large (L) = 10 min/ply
Medium (M) = 5 min/ply
Small (S) = 2 min/ply

(e) 16 ply precut laminates are considered as large pieces and require additional 30 minutes for layup.

(f) Price includes G & A costs.

(g) Only manufacturing differences are shown; similar operations between production and pultruded designs are not indicated in comparison.

(h) Total number of potential aircraft with pultruded spars:

UH-60A BLACK HAWK (incorporated on A/C #300)		807 A/C
SOTAS		123 A/C
SH-60A		203 A/C
	Total Aircraft	1134 A/C
	10% Spares	113 A/C
	Anticipated Total	1247 A/C

(i) Only recurring costs are considered in this cost comparison. Non-recurring expenditures, such as tooling, are not included in the cost comparison. Existing tooling with minimum modification would be used. The cost comparison also assumes that the new pultrusion resin development and manufacturing risk reduction programs would be completed by mid-1981 and that the pultruded resin system developed is similar to the existing prepreg systems.

TABLE 20. PULTRUDED DESIGN PART BREAKDOWN

Major Assemblies		P/N-38013-00005		Components		
-041		-042				
DASH NO. Subassy.	(No. of Plies) X No. of Sub-assy's. req'd.	DASH NO. Subassy.	(No. of Plies) X No. of Sub-assy's. req'd.	LOCATION	SIZE (Inch) (Length) X (Width)	ORIENTATION (Deg.)
-043	(42) X 1	-043	(42) X 1	Center Sub Assy. #104 thru #145	(12 to 30) X (1½)	0, ± 20
-044	(-) X 4	-044	(-) X 4	Pultrusion	(125) X (1½)	0
-045	(16) X 2	-045	(16) X 2	Torpedo Hub #246T	(44) X (1½)	C
-046	(8) X 2			Filler Rib-Lower #149 thru #156	(6 to 7) X (6)	± 45
-047	(39) X 2			Center Subassy. Rib #157 thru #195	(7 to 7½) X (6)	± 45
-048	(8) X 2			Filler Rib-Upper #196 thru #203	(6½ to 7½) X (6)	± 45
-049	(16) X 4			Filler Rib #247	(8½) X (2½)	0
-050	(16) X 4			Filler Rib #248	(7) X (3/8)	0
		-051	(8) X 2 (21) X 2	Filler Rib-Lower #149 thru #156 #207 thru #227	(6½ to 7) X (6) (7 to 10) X (6)	± 45 ± 45
		-052	(8) X 2 (18) X 2	Filler Rib-Upper #196 thru #203 #228 thru #245	(6½ to 7) X (6) (7½ to 10) X (6)	± 45 ± 45
		-053	(32) X 2	Filler Rib #249	(8½) X (2½)	0
		-054	(32) X 2	Filler Rib #250	(8½) X (3/8)	0
-101, -102	(1) X 1 each	-101, -102	(1) X 1 each	Skin Ply	(125) X (6)	0
-103, 146	(1) X 1 each	-103, 146	(1) X 1 each	Skin Ply	(40) X (6)	0
-147 & 148	(1) X 1 each	-148	(1) X 1 each	Skin Ply	(125) X (6)	0
204, 206	(1) X 1 each	-204, 206	(1) X 1 each	Sacrificial Plies	(6½) X (6)	90
205	(1) X 1	205	(1) X 1	Sacrificial Ply	(6½) X (6)	0
Total Plies → 321		Total Plies → 321				

CONCLUSIONS

This program successfully demonstrated the technology for the applicability of the pultrusion fabrication process to the manufacture of a fiber-reinforced plastic helicopter tail rotor assembly.

The cost effectiveness and producibility of the pultrusion process as compared with present BLACK HAWK production technique are not significant enough to warrant a change in manufacturing fabrication of the tail rotor spar at this point in time.

Designs that involve significant ply orientation changes through the thickness make it difficult for pultrusion processing to compete with standard layup techniques. Increased handling of smaller layers decreases the anticipated economic benefits.

Additional work on development of an adequate resin system would be required prior to incorporation of the pultrusion process into the production fabrication of flexbeam tail rotor spar assemblies.

RECOMMENDATION

Efforts should be directed toward developing an adequate pultrusion resin system that can meet current elevated temperature and environmental requirements while maintaining an adequate shelf life.

LIST OF SYMBOLS

AS	Graphite Filament Type A (Hercules Identification) With Surface Treatment
"B" staged	Uncured Pultrusion
CF	Centrifugal Force
cps	Centipoise
dB	Decibel
E_B	Flexural Modulus
Epon 826	Shell Epoxy Resin System
F_V	Fiber Volume
G	Torsional Modulus
ksi	Thousand Pounds Per Square Inch
M_{EB}	Maximum Edgewise Bending
M_{FB}	Maximum Flatwise Bending
MPD/DMF	M-Phenylenediamine/Dimethyl Formamide, Resin Curing Agents
MS	Margin of Safety
R	Stress Ratio
RT	Room Temperature
STA	Station - Denotes Dimensional Location in Inches with Respect to Distance of the Centerline of Rotation
ϕ	Blade Angle From Horizontal
μ	Strain, inch per inch

730-80